CHALMERS
UNIVERSITY OF TECHNOLOGY

Traction Motor for a Battery Electric City Bus

Specification and Drive Cycle Evaluation, Based on Comprehensive Data Collection

Report for the FFI project Electric Traction Motors in a Circular Economy

EMMA ARFA GRUNDITZ

DEPARTMENT OF ELECTRICAL ENGINEERING
DIVISION OF ELECTRIC POWER ENGINEERING

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2020
www.chalmers.se

Traction Motor for a Battery Electric City Bus
Specification and Drive Cycle Evaluation, Based on Comprehensive Data Collection

Report for the FFI project Electric Traction Motors in a Circular Economy, nr. 44204-1

Technical report 2020:1
Department of Electrical Engineering
Division of Electric Power Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
SE-412 96 Gothenburg
Sweden, 2020

Abstract

This internal, yet official, report serves as base for selecting the specification of a propulsion electric motor for a typical Battery Electric City Bus (BECB). The motor and the bus data are used as references in the research project *Circular Economy for Electric Machines*, sponsored by the Swedish Energy Agency. Additionally, found official bus drive cycles are presented and characterized, as well as four logs of real world driving of a battery electric city bus in Gothenburg, Sweden. Then, the energy consumption of the reference bus with the reference electric motor efficiency map are calculated and compared to found official data on energy consumption of similar size battery electric city buses. Finally, related bus and electric bus market statistics and projections are summarized. In general, this report aim to provide background data for further analysis, which is why deeper analysis is left out of the report.

Contents

Chapter 1

Introduction

This is an internal report for Work Package 2 (WP2) and WP6 in the project *Circular Economy for Electric Machines*.

1.1 Project: Circular Economy for Electric Machines

The project is a senior research project, formed as a collaboration between the two divisions; Environmental System Analysis and Electric Power Engineering at Chalmers University of Technology, financed by the Swedish Energy Agency via it's program *Fordonsstrategisk Forskning och Innovation (FFI)* (direct translation to English; Vehicle Strategic Research and Innovation). The project scope is to study the environmental consequences that different vehicle propulsion electric machine types/designs have on the machines full life cycle, including end-of-life.

1.2 WP2 - Requirements on Traction Electric Machines for Vehicles

In this work package, the requirements on the studied machines are to be investigated and identified, both for a battery electric light and a heavy duty vehicle, in terms of a typical passenger car and city bus. This internal project report aims to define the electric machine requirements for the battery electric city bus (BECB).

Therefore, initially a typical vehicle has to be decided upon along with it's performance requirements such as top speed, gradeability and time to accelerate from stand still to 100 km/h. From this information, the vehicle's wheel force as a function of speed can be calculated, as well as the needed wheel power. Then a suitable tire radius must be defined.

The radius together with a suitable gear ratio is used to convert the wheel force and speed to electric machine torque and speed requirements. The machine torque and power rating must be slightly larger than the needed wheel torque and power, due to gear losses.

Also the electrical input from the battery dc-bus via the inverter to the machine has to be specified in order to be able to make a full electric machine design.

Preferably, the same electrical input and mechanical output requirements are fulfilled by all studied machine types, with only minor adjustments.

As a basis to determine these machine requirements and design specifications, a large number of commercial BECBs have been studied and the findings are summarized in this report.

1.3 WP6 - Use Phase LCA

In WP6, the energy consumption of the conceptualized BECB will be estimated when equipped with the different electric machines studied. This will be done by calculating the electric machine's energy losses during a certain drive cycle. Therefore, additionally in this report, a large number of official bus drive cycles are described and compared. Furthermore, four in-house drive cycle collections have been made with a GPS logger, when riding electric buses in Gothenburg, Sweden, during 2018.

Additionally, specification data of BECB energy consumption, battery energy and driving range is also collected on the commercial BECBs as a frame of reference for the Life Cycle Assessment (LCA) use phase calculations. Data on charging is however not presented here.

1.4 Structure of this report.

The report structure is described in Table 1.1.

Table 1.1: Report structure.

	Chapter title	**Summary of content**
Ch.1	Introduction	Introduction to the report
Ch.2	Market Overview - Electric City Buses	Summary of published statistics and projections presented in Appendix A. Data on electric bus manufacturer market shares, and most sold bus lengths. Specification data on 93 commercial battery electric city bus models of length 10-13m, regarding dimensions, performance, battery and electric motor. Data on most commonly used electric motor manufacturers and models.
Ch.3	Requirements on the Reference Electric Machine for a Battery Electric City Bus	Derivation of the requirements on firstly a reference battery electric city bus, and secondly a reference electric machine for that bus, both based on data presented in Chapter 2 and Appendix A.
Ch.4	Bus Drive Cycles - Official	Data and overview of several official city bus drive cycles
Ch.5	Bus Drive Cycles - Logged in Gothenburg, Sweden	Data and overview of four logged electric bus drive cycles
Ch.6	Bus Drive Cycle Energy Consumption	Published battery energy consumption of commercial battery electric buses, and calculated battery energy consumption with reference bus and electric motor for official and logged drive cycles
App.A	Bus Statistics	Statistics and projection for buses and electric buses regarding total fleet, annual production/sales/orders, along with annual bus travellers per region.
App.B	The ZeEUS eBus Report Data - Illustrated	Summary and illustration of statistics published in *ZeEUS eBus Report 2* [1] which covers test runs with electric city buses in European cities.
App.C	BEV Bus Specifications	Selected specification data on 53 found city buses shorter than 10m and longer than 13m, as well as 17 battery electric coach buses.

Chapter 2

Market Overview - Electric City Buses

This section begins with a summary of the background statistics presented in Appendix A, which cover topics such as total number and localization of buses and electric buses as well as predictions of electric bus sales. Next follows further statistics regarding most common electric bus suppliers and sold bus lengths, as well as detailed specifications on over 90 battery electric city bus models, 10-13 m long, followed by an investigation of the most common electric drive systems.

2.1 Summary of Statistics in Appendix A

The motivation for investigating the battery electric city bus segment is based on statistics and projections of the bus sector, as presented in Appendix A. Here follows a short list of key figures and points:

- Latin America has the largest number of daily bus travellers [2]
- In 2016 the global bus fleet consisted of about 10.4 million busses, and almost half of them were used in Asia, in particular China [3] [4]. About 345 000 of them were electric, i.e. 3.3% [5]. Over 99% of the electric buses were used in China in 2016 [5].
- In Europe, countries like United Kingdom, the Netherlands, Germany and France had the largest number of electric buses in 2017, and about 70% of them were of battery electric or fuel cell type [6] [7].
- About 350 000 buses are produced annually in the world, and about 70% of them are produced in Asia (and Oceania) [8]. In 2017, 106 000 electric buses (battery electric and plug-in hybrid) were sold in China [7].
- In Europe the number of ordered electric buses per year has increased by 50%-70% each year between 2013-2016, and in 2017 by about 160% [6].
- In China, the market share of sold electric buses (battery electric and P-HEV) was about 28% in 2016 and 23% in 2017 [7].
- The global electric bus fleet was predicted to triple between 2017 and 2025 (by Bloomberg in 2018 A.7), and to increase by 69% in Europe (by Statista and Frost&Sullivan in 2016 [9, 10]).
- Battery electric buses has been predicted to dominate the global electric bus segment through 2016-2026 (by Navigant Research in 2016 [11]), as well as to constitute at least half of the bus fleet in Europe in 2030 (by ZeEUS and the UITP VEI Committee's in 2018 [1]).

2.2 Electric Bus Sales - Manufacturers, Models, Length

2.2.1 Europe

According to data collected and presented by Stefan Baguette (Market Analyst and Product Manager at Alexander Dennis Limited, ADL), the market share per electric bus manufacturer in Europe at the end of 2017 is presented in Figure 2.1 [6].

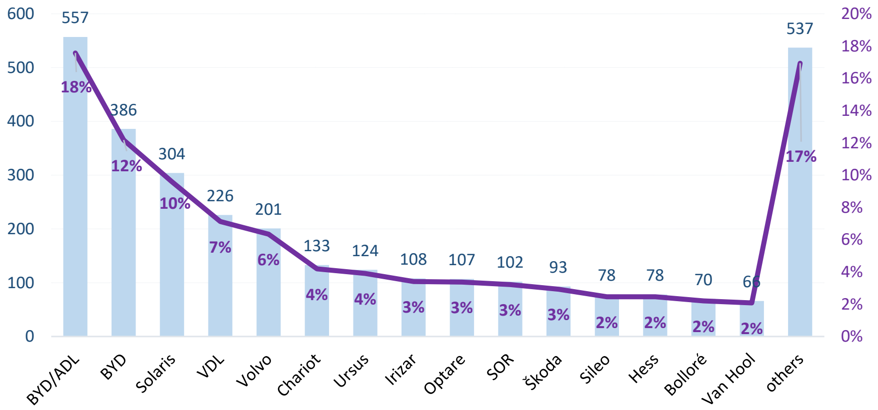


Figure 2.1: European electric bus suppliers, at end of 2017 [6]. Left axis: units sold, right axis: market share.

Furthermore, according to data collected and presented by *electrive.com*, the market share per electric bus supplier in Europe 2018 is presented in Figure 2.2 [12]. Compared to the above reference, here, two additional manufacturers are claimed to be amongst the most frequently used; Yutong and Hess.

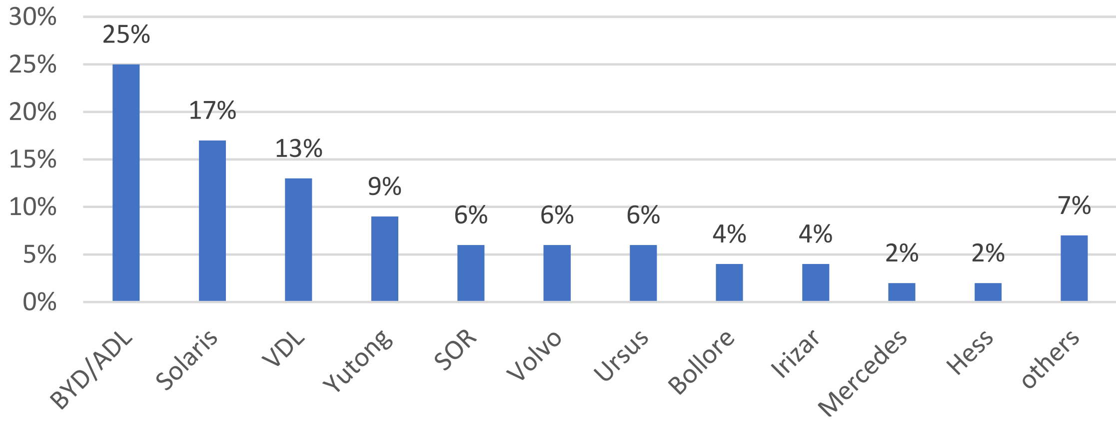


Figure 2.2: Market shares for electric bus suppliers in Europe during 2018 [12].

2.2.2 China

Data on sold units and market shares for electric bus manufacturers in China was found for 2015 and 2016, and is shown in Figure 2.3 from Bloomberg [7].

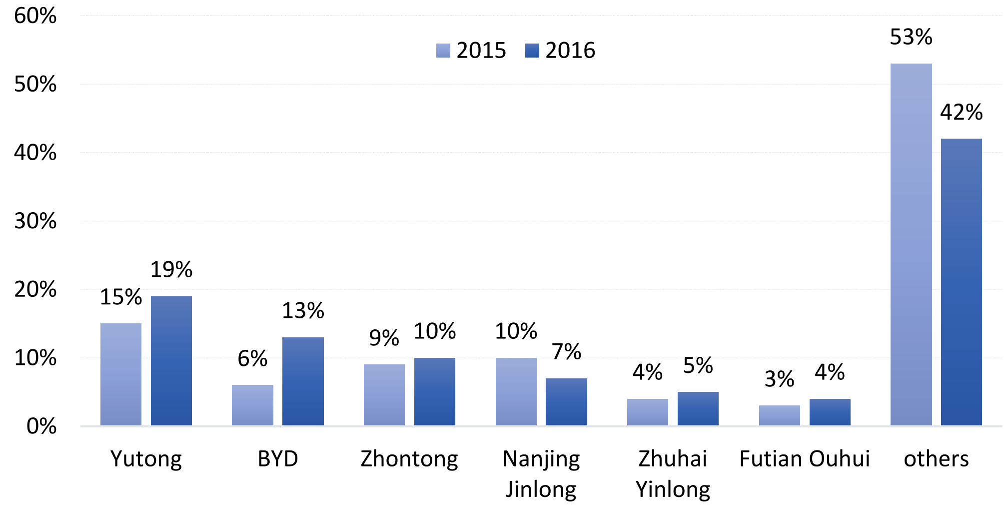


Figure 2.3: Market shares for electric bus manufacturers in China 2015 and 2016 [7].

As a reference, data on market share 2016 was also found from SCI [3], and is shown in Figure 2.4.

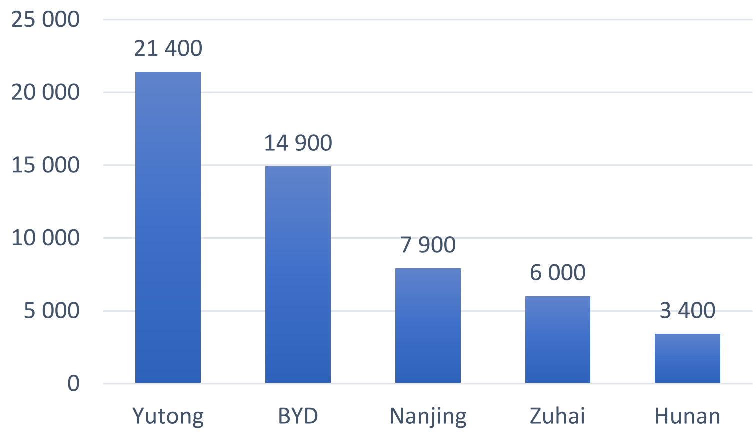


Figure 2.4: Delivered electric busses in China, per manufacturer in 2016 [3].

2.2.3 BEV Bus Length

According to data collected and presented by Stefan Baguette (Market Analyst and Product Manager at Alexander Dennis Limited, ADL), the number of ordered battery electric buses in Europe 2017, per bus length, is presented in Figure 2.5 [6].

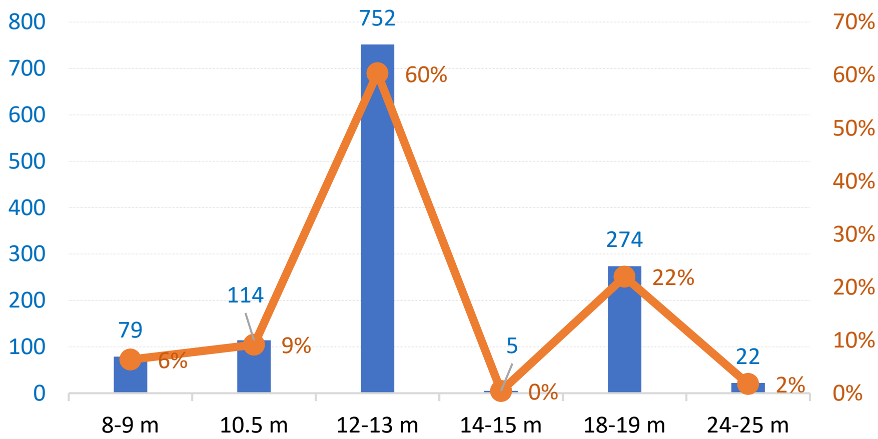


Figure 2.5: The number of ordered BEV buses 2017 per bus length [6]. *Left;* total number, *Right;* share of total number.

According to the *ZeEUS eBus Report #2*, the number of different length battery electric city buses tested in Europe during the last few yeas, is presented in Figure B.4.

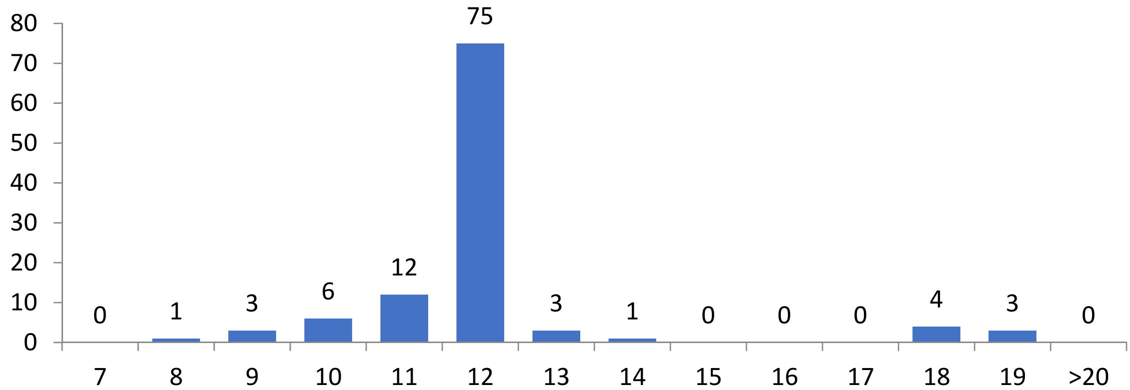


Figure 2.6: Total number of electric buses tested per bus length (in bins of 1m) [1].

Due to the seen dominance of 12 m long city buses, the focus in the rest of this report is on them.

2.3 Commercial Battery Electric City Buses (BECB's), 10-13m

In this section, the specifications of 93 battery electric city buses of length 10-13m are divided into 4 different data categories; dimensional, performance, electric machine, and battery, are listed. Naturally, complete data could not be found in all categories for all bus models. Furthermore, despite the noted dominance of BECBs in China, most data seen has been found for models from other countries.

Furthermore, selected specifications for 53 shorter and longer battery electric city buses, and for 17 battery electric coach buses are presented in Appendix C, along with a short list of non included bus models due to lack of data at the time of work.

Table 2.1: Dimensional specifications of studied battery electric city buses (10-13m long). (Skywell Nanjing Golden Dragon is abbreviated to Skywell Nan.Gol.Dra.)

	Bus Brand	Bus Model	Curb weight (kg)	Max/ Gross Weight (kg)	Max. Pass.	Seats	Width (m)	Height (m)	Length (m)	Tire size
FR	Alstom NTL	APTIS			95[13]		2.55[13]	3.10[13]	12.00 [1]	
CN	Ankai	HFF6123G03EV-2		18 000[14]	37[14]		2.50[14]	3.15[14]	12.00[14]	275/70R22.5 [14]
AU	Avass	Metro Bus Series	12 750[15]	18 000[15]	70[15]		2.50[15]	3.25[15]	12.00[15]	
AU	Avass	Matilda City Bus		20 000[16]	66[16]	42[16]	3.12[16]	2.50[16]	12.50[16]	295/80R22.5 [16]
FR	Bollore	Bluebus 12m		20 000[17]	101[17]		2.55[17]	3.10[17]	12.00[17]	
CA	Bombardier, Hess	Primove	12 000[18]		80[18]	36[18]			12.00[18]	
TR	Bozankaya A.S.	Sileo S10		19 500[19]	90[19]	33[19]	2.55[19]	3.21[19]	10.75[19]	275/70R22.5 [19]
TR	Bozankaya A.S.	Sileo S12		19 500[20]	90[20]	39[20]	2.55[20]	3.21[20]	12.22[20]	275/70R22.5 [20]
IT	BredaMenarinibus	Citymood 12 E	14 000[21]		72[21]	32[21]	2.55[21]	3.39[21]	12.10[21]	
FR	Businova	Midibus L					2.55[22]	3.20[22]	10.55[22]	
CN	BYD	K9	13 800[23]	18 000[23]		29[23]	2.50[23]	3.20[23]	12.00[23]	275/70R22.5 [23]
CN	BYD (Europe)	LE 2 doors		19 000[24]	90[24]	36[24]	2.55[24]	3.36[24]	12.05[24]	275/70R22.7 [24]
CN	BYD (SG)	K9	13 100[25]	18 000[25]		35[25]	2.50[25]	3.40[25]	12.00[25]	275/70R22.6 [25]
CN	BYD USA	40"	14 000[26]	19 700[26]		41[26]	2.58[26]	3.52[26]	12.47[26]	305/70R22.5 [26]
PT	Caetano	e. City Gold		19 000 [1]	88[27]	40[28]	2.50[28]	3.38[28]	12.00 [1]	275/70R22.5 [27]
US	Chariot Motors	12m (Siemens)	12 540[29]	18 000[29]	82[29]	29[29]	2.55[29]	3.68[29]	12.00[29]	275/70R22.5 [29]
US	Chariot Motors	12m (ZF)	12 540[29]	18 000[29]	82[29]	29[29]	2.55[29]	3.68[29]	12.00[29]	275/70R22.5 [29]
CN	DFAC	EQ6100CACBEV	10 700[30]	16 500[30]	72[30]	38[30]	2.50[30]	3.04[30]	10.48[30]	
DE	ebeEUROPA	BlueCityBus	13 065[31]	18 000[32]	80[32]	35[32]	2.55[32]	3.27[32]	11.98[32]	455/45R22.5 [32]
NL	Ebusco	2.1 LF-311-HV-2/3	12 300[33]	19 000[34]	90 [1]	41[33]	2.55[33]	3.27[33]	11.98[34]	
CZ	Ekova	Electron 12m		18 000[35]	90[35]	30[35]	2.55[35]	3.27[35]	11.98[35]	275/70R22.5 [35]
CN	Golden dragon	XML6125CLE (Ebusco 2.1)	12 275[36]	19 000[36]	40[36]	39[36]	2.54[36]	3.28[36]	11.98[36]	275/70R22.5 [36]
CN	Golden dragon	BEV		17 800[37]		24[37]	2.54[37]	3.12[37]	12.00[37]	
CA	GreenPower	EV300	14 207[38]			34[39]	2.59[39]	3.26[39]	10.67[39]	
CA	GreenPower	EV350				40[39]	2.59[39]	3.26[39]	12.19[39]	315/80R22.5 [38]
CN	Guangtong	GTQ6105BEVBT2	10 800[40]	16 500[40]	80[40]		2.50[40]	3.15[40]	10.18[40]	275/70R22.5 [40]
CN	Guangtong	GTQ6105BEVB2	10 800[40]	16 500[40]			2.50[40]	3.15[40]	10.48[40]	275/70R22.5 [40]
CN	Guangtong	GTQ6105BEVB3	10 800[40]	16 500[40]	80[40]		2.50[40]	3.15[40]	10.48[40]	275/70R22.5 [40]
CN	Guangtong	GTQ6105BEVBT	10 800[40]	16 500[40]	80[40]		2.50[40]	3.15[40]	10.50[40]	275/70R22.5 [40]
CN	Guangtong	GTQ6121BEVB2	12 700[40]	18 000[40]	80[40]	24[40]			12.00[40]	295/80R22.5 [40]
CN	Guangtong	GTQ6121BEVBT	12 500[40]	18 000[40]	80[40]		2.54[40]	3.04[40]	12.00[40]	295/80R22.5 [40]
CN	Guangtong	GTQ6121BEVBT2	12 500[40]	18 000[40]	80[40]		2.54[40]	3.04[40]	12.00[40]	275/70R22.5 [40]
FR	Heuliez	GX 337 ELEC		20 000 [1]	94 [1]		2.55[41]	3.40[41]	12.00 [1]	
CN	Higer	KLQ6125GEV		19 000[42]	90[42]	27[42]	2.55[42]	3.63[42]	12.00[42]	
CN	Hunan CRRC	TEG6125BEV03		18 000 [1]	81 [1]		2.50[43]	3.30[43]	12.00 [1]	
CN	Hunan CRRC	TEG6129BEV03		19 000 [1]	94 [1]	37[43]	2.50[43]	3.30[43]	12.00 [1]	
SE	Hybricon	HAW 12 LE		18 000[44]	74[44]	33[44]	2.55[44]	3.30[44]	12.00[44]	455/45R22.5 [44]
SE	Hybricon	HAW 12 LF		18 000[44]	75[44]	32[44]	2.55[44]	3.30[44]	12.00[44]	455/45R22.6 [44]
SE	Hybricon	HCB 12 LE		18 000[44]	86[44]	32[44]	2.55[44]	3.30[44]	12.00[44]	455/45R22.8 [44]
SE	Hybricon	HCB 12 LF		18 000[44]	90[44]	28[44]	2.55[44]	3.30[44]	12.00[44]	455/45R22.9 [44]
SE	Hybricon	HCB 12 LF		18 000 [1]	62 [1]				12.00 [1]	
ES	Irizar	10			76[45]		2.55[45]	3.21[45]	10.85[45]	
ES	Irizar	ie (prev. i2e)		20 000 [1]	82[45]		2.55[45]	3.21[45]	11.98 [1]	
CN	King Long	XMQ6106G EV				40[46]	2.50[46]	3.07[46]	10.50[46]	
CN	King Long	VMQ6111G EV				39[46]	2.50[46]	3.07[46]	10.70[46]	
CN	King Long	XMQ6127G EV				45[46]	2.55[46]	3.07[46]	11.98[46]	
FI	Linkker Oy	Linkker 12+ LE	10 500[47]	16 000 [1]	80 [1]	43[47]	2.55[47]		12.82[47]	
DE	Mercedes-Benz	eCitaro	13 440[48]	19 500[48]	88[48]	29[49]	2.55[49]	3.40[49]	12.14[49]	275/70R22.5 [49]
US	New Flyer	35" 11m	13 066[50]	19 960[50]	65[51]	32[51]	2.60[51]	3.38[51]	11.05[51]	305/70R22.5 [51]
US	New Flyer	40" 12m	14 855[52]	20 103[52]	83[51]	40[51]	2.60[51]	3.38[51]	12.24[51]	305/70R22.5 [51]
GB	Optare	Metrocity EV MC 10130		10 780[53]	60[53]	36[53]	2.47[53]	2.85[53]	10.13[53]	245/70R19.5 [53]
GB	Optare	Metrocity EV MC 10820		12 960[53]	60[53]	40[53]	2.47[53]	2.85[53]	10.82[53]	245/70R19.5 [53]
GB	Optare	Metrocity EV MC 11520		12 960[53]	60[53]	44[53]	2.47[53]	2.85[53]	11.52[53]	245/70R19.5 [53]
GB	Optare	Solo EV standard		10 780[53]	58[53]	36[53]	2.50[53]	2.89[53]	9.96[53]	235/75R17.5 [53]
GB	Optare	Versa EV		12 960 [1]	57[53]	44[53]	2.50[53]	2.85[53]	11.79[53]	245/70R19.5 [53]
US	Proterra	Catalyst 35" E2	14 374[54]	17 917[54]		40[54]		3.40[54]	11.25[54]	
US	Proterra	Catalyst 35" FC	13 456[54]	17 917[54]		28[54]		3.45[54]	11.25[54]	
US	Proterra	Catalyst 35" FC+	14 374[54]	17 917[54]		28[54]		3.45[54]	11.25[54]	
US	Proterra	Catalyst 35" XR	12 710[54]	17 917[54]		28[54]		3.45[54]	11.25[54]	
US	Proterra	Catalyst 35" XR+	13 456[54]	17 917[54]		28[54]		3.45[54]	11.25[54]	
US	Proterra	Catalyst 40" FC	13 320[55]	19 503[55]		40[55]		3.40[55]	11.25[55]	
US	Proterra	Catalyst 40" E2	14 061[55]	19 799[55]		40[55]		3.40[55]	12.95[55]	
US	Proterra	Catalyst 40" E2 max	14 996[55]	19 799[55]		40[55]		3.40[55]	12.95[55]	
US	Proterra	Catalyst 40" E2+	14 255[55]	19 799[55]		40[55]		3.40[55]	12.95[55]	
US	Proterra	Catalyst 40" FC+	14 061[55]	19 799[55]		40[55]		3.40[55]	12.95[55]	
US	Proterra	Catalyst 40" XR	12 578[55]	19 503[55]		40[55]		3.40[55]	12.95[55]	
US	Proterra	Catalyst 40" XR+	13 320[55]	19 503[55]		40[55]		3.40[55]	12.95[55]	
IT	Rampini	E120		19 000[56]	73[56]	32[56]	2.55[57]	3.39[57]	12.10[57]	
CZ	ŠKODA	ŠKODA Perun HE		18 600 [1]	82 [1]	27[58]	2.55[58]	3.25[58]	12.00 [1]	
CZ	ŠKODA	ŠKODA Perun HP		18 600 [1]	82 [1]	27[59]	2.55[58]	3.25[58]	12.00 [1]	
CN	Skywell Nan.Gol.Dra.	NJL6100BEV30			75[60]		2.55[60]	3.20[60]	10.49[60]	
CN	Skywell Nan.Gol.Dra.	NJL6100BEV36	12 500[61]	16 500[61]	65[60]		2.55[60]	3.20[60]	10.49[60]	11R22.5 [61]
CN	Skywell Nan.Gol.Dra.	NJL6100BEV39			65[60]		2.55[60]	3.20[60]	10.49[60]	
CN	Skywell Nan.Gol.Dra.	NJL6100BEV43			95[60]		2.55[60]	3.20[60]	10.49[60]	
PL	Solaris	Urbino 12 electric		19 000 [1]	90 [1]	37[62]	2.55[62]	3.30[62]	12.00 [1]	
CZ	SOR	SOR EBN 11	10 500[63]	16 500 [1]	90 [1]	33[64]	2.53[64]	2.92[64]	11.10 [1]	285/70R19.5 [64]
CZ	SOR	NS 12 electric		18 800[63]		35[63]	2.55[63]	3.20[63]	12.00[63]	275/70R22.5 [63]
TR	TEMSA	Temsa Avenue EV		18 600[65]	90 [1]	35[65]	2.55[65]	3.20[65]	12.00 [1]	275/70R22.5 [65]
SK	Troliga	Leonis Electric	13 000[66]	19 000[66]	94[66]	30[66]	2.55[66]	3.01[66]	12.00[66]	455/45R22.5 [66]
PL	URSUS	Ekovolt E70110		18 000 [1]	81 [1]		2.55[67]	3.36[67]	11.96 [1]	275/70R22.5 [67]
PL	URSUS	City Smile 9.95m		18 000 [1]	84 [1]				9.95 [1]	
PL	URSUS	City Smile 12m 62p	13 000[67]	18 000 [1]	76[67]		2.55[67]	3.50[67]	12.00 [1]	455/45R22.5 [67]
PL	URSUS	City Smile 12m 82p	12 400[67]	18 000 [1]	82 [1]		2.55[67]	3.50[67]	12.00 [1]	275/70R22.5 [67]
NL	VDL	Citea SLF-120 Electric	10 000[68]	14 870[68]	63 [1]		2.55[68]	3.36[68]	9.95 [1]	
NL	VDL	Citea SLFA-180 Electric	12 715[68]	19 500[68]	92 [1]		2.55[68]	3.29[68]	12.00[68]	
SE	Volvo	10.7m		18 000[69]			2.55[69]	3.30[69]	10.72[69]	275/70R22.5 [69]
SE	Volvo	7900 Electric		19 000[70]	105[70]	34[70]	2.55[70]	3.28[70]	12.00[70]	275/70R 22.5[70]
CN	Wuzhoulong	FDG6113EVG		18 000[71]	58[71]	36[71]	2.48[71]	2.91[71]	11.49[71]	295/80R22.5 [71]
CN	YinLong	12m	15 000[72]	18 000[72]	76[72]	42[72]	2.55[72]	3.45[72]	12.00[72]	
CN	YinLong	12m		18 000[72]	84[72]	42[72]	2.54[72]	3.05[72]	12.00[72]	
CN	Yutong	ZK6105BEVG				33[73]	2.50[73]	3.28[73]	10.86[73]	275/70R22.5 [73]
CN	Yutong	E12	13 300[74]	19 700[74]	97[74]	33[74]	2.55[74]	3.34[74]	12.00[74]	275/70R22.5 [74]
CN	Zhong Tong	LCK6122EVG		18 000[75]	70[75]	42[75]	2.54[75]	3.28[75]	11.99[75]	275/70R22.5 [75]

Table 2.2: Performance specifications of studied battery electric city buses (10-13m long). (Skywell Nanjing Golden Dragon is abbreviated to Skywell Nan.Gol.Dra.)

	Bus Brand	Bus Model	Top speed (km/h)	Time (0-X km/h) (s)	Max. Grade (%)	Energy/ dist (kWh/km)	Range (km)	Peak Power/ GVW (W/kg)	Peak Power/ Curb Weight (W/kg)	AC max. Power (kW)	Heat max. Power (kW)
FR	Alstom NTL	APTIS	70[13]		20[13]		200 [1]				
CN	Ankai	HFF6123G03EV-2	69[14]								
AU	Avass	Metro Bus Series	80[15]	18(0-50)[15]	20[15]		300[15]	11.1	15.7		
AU	Avass	Matilda City Bus	100[16]				250[16]	9.0			
FR	Bollore	Bluebus 12m	70[17]				250[76]	8.0			
CA	Bombardier, Hess	Primove							23.3		
TR	Bozankaya A.S.	Sileo S10	75[19]			0,75[19]	280[19]	12.8			
TR	Bozankaya A.S.	Sileo S12	75[20]			0.8[20]	280[20]	12.8			
IT	BredaMenarinibus	Citymood 12 E	80[21]		18[21]				11.4	15.2[21]	14.9[21]
FR	Businova	Midibus L									
CN	BYD	K9	70[23]	23(0-50)[23]	15[23]	1.20[23]	250[23]	10.0	13.0		
CN	BYD (Europe)	LE 2 doors	80[24]		17[77]			15.8			
CN	BYD (SG)	K9	70[25]		20[25]		250[25]	16.7	22.9		
CN	BYD USA	40"	100[26]		18[26]		410[26]	7.6	21.4		
PT	Caetano	e. City Gold	70[27]				200[27]	8.4			
US	Chariot Motors	12m (Siemens)	73 [1]			0.95[29]		10.0	14.4		20[29]
US	Chariot Motors	12m (ZF)	72 [1]			0.95[29]		13.9	19.9		20[29]
CN	DFAC	EQ6100CACBEV	69[30]				260[30]	9.1	14.0		
DE	ebeEUROPA	Blue City Bus	81[32]			0.9[32]	300[32]	10.1	13.9	25[31]	
NL	Ebusco	2.1 LF-311-HV-2/3	80 [1]	6(0-30)[33]	18[33]	0.85 [1]	250[33]	11.6	17.9		
CZ	Ekova	Electron 12m									
CN	Golden dragon	XML6125CLE (Ebusco 2.1)					300[36]	7.9	12.2		
CN	Golden dragon	BEV	69[78]		15[78]		260[78]				
CA	GreenPower	EV300	96[38]				280[39]		21.1		
CA	GreenPower	EV350					300[39]				
CN	Guangtong	GTQ6105BEVBT2	69[40]								
CN	Guangtong	GTQ6105BEVB2	69[40]								
CN	Guangtong	GTQ6105BEVB3	69[40]								
CN	Guangtong	GTQ6105BEVBT	69[40]								
CN	Guangtong	GTQ6121BEVB2	69[40]					8.6	12.2		
CN	Guangtong	GTQ6121BEVBT	69[40]								
CN	Guangtong	GTQ6121BEVBT2	69[40]								
FR	Heuliez	GX 337 ELEC	80 [1]				200 [1]	9.5			
CN	Higer	KLQ6125GEV	70[42]					6.3			
CN	Hunan CRRC	TEG6125BEV03	70 [1]			1.2 [1]	115 [1]	8.3			
CN	Hunan CRRC	TEG6129BEV03	70 [1]				116 [1]	7.9			
SE	Hybricon	HAW 12 LE						20.2			
SE	Hybricon	HAW 12 LF						20.2			
SE	Hybricon	HCB 12 LE						20.2			
SE	Hybricon	HCB 12 LF						40.4			
SE	Hybricon	HCB 12 LF	80 [1]					17.4			
ES	Irizar	10			18[45]					38.5[45]	36[45]
ES	Irizar	ie (prev. i2e)	85 [1]		18[45]	1.5 [1]		8.0		38.5[45]	36[45]
CN	King Long	XMQ6106G EV	69[46]		15[46]						
CN	King Long	VMQ6111G EV	68[46]		15[46]						
CN	King Long	XMQ6127G EV	69[46]		15[46]						
FI	Linkker Oy	Linkker 12+ LE	80 [1]			1.1 [1]			17.1		
DE	Mercedes-Benz	eCitaro					150[48]	12.8	18.6		
US	New Flyer	35" 11m					309[50]				
US	New Flyer	40" 12m		7.8(0-32)[52]	10[52]	1.14[52]	418[79]	9.5	12.8		
GB	Optare	Solo EV standard	95[53]					20.4			
GB	Optare	Metrocity EV MC 10130	95[53]			0.67 [1]	240[53]	20.4			
GB	Optare	Metrocity EV MC 10820	95[53]				240[53]	17.0			
GB	Optare	Metrocity EV MC 11520	95[53]				240[53]	17.0			
GB	Optare	Versa EV	95[53]			0.67 [1]	240[53]	17.0			
US	Proterra	Catalyst 35" E2	105[54]	4.5(0-32)[54]	25[54]	0.91[54]	486[54]	21.2	26.5		
US	Proterra	Catalyst 35" FC	105[54]	4.5(0-32)[54]	27[54]	0.87[54]	108[54]	15.0	20.0		
US	Proterra	Catalyst 35" FC+	105[54]	4.5(0-32)[54]	25[54]	0.91[54]	138[54]	21.2	26.5		
US	Proterra	Catalyst 35" XR	105[54]	4.5(0-32)[54]	28[54]	0.84[54]	262[54]	10.0	14.1		
US	Proterra	Catalyst 35" XR+	105[54]	4.5(0-32)[54]	27[54]	0.87[54]	378[54]	15.0	20.0		
US	Proterra	Catalyst 40" FC	105[55]	4.5(0-32)[55]	27[55]	0.86[55]	109[55]	13.8	20.2		
US	Proterra	Catalyst 40" E2	105[55]	4.5(0-32)[55]	26[55]	0.89[55]	491[55]	19.2	27.1		
US	Proterra	Catalyst 40" E2 max	105[55]	4.5(0-32)[55]	23[55]	0.96[55]	686[55]	19.2	25.4		
US	Proterra	Catalyst 40" E2+	105[55]	4.5(0-32)[55]	25[55]	0.93[55]	591[55]	19.2	26.7		
US	Proterra	Catalyst 40" FC+	105[55]	4.5(0-32)[55]	26[55]	0.89[55]	140[55]	19.2	27.1		
US	Proterra	Catalyst 40" XR	105[55]	4.5(0-32)[55]	28[55]	0.83[55]	264[55]	9.2	14.2		
US	Proterra	Catalyst 40" XR+	105[55]	4.5(0-32)[55]	27[55]	0.86[55]	383[55]	13.8	20.2		
IT	Rampini	E120	80[56]				150[56]	8.4		15.2[56]	14[56]
CZ	ŠKODA	ŠKODA Perun HE	80[80]			1.4 [1]	150[80]	8.6			
CZ	ŠKODA	ŠKODA Perun HP	80[59]			1.4 [1]	300[58]	8.6			25[59]
CN	Skywell Nan.Gol.Dra.	NJL6100BEV30									
CN	Skywell Nan.Gol.Dra.	NJL6100BEV36	69[61]					6.1	8.0		
CN	Skywell Nan.Gol.Dra.	NJL6100BEV39									
CN	Skywell Nan.Gol.Dra.	NJL6100BEV43									
PL	Solaris	Urbino 12 electric	80 [1]			0.9 [1]		13.2			
CZ	SOR	SOR EBN 11	80[64]			1.1 [1]		7.3	11.4		
CZ	SOR	NS 12 electric	80[63]					8.5			
TR	TEMSA	Temsa Avenue EV	90 [1]		18[65]	1.5 [1]		13.4		35[65]	35[65]
SK	Troliga	Leonis Electric	90[66]			0.9[66]	320[66]				
PL	URSUS	City Smile 9.95m	70 [1]					6.7			
PL	URSUS	Ekovolt E70110	70 [1]			0.97 [1]		13.9		26[67]	
PL	URSUS	City Smile 12m 62p	100 [1]					40.4	56.0		
PL	URSUS	City Smile 12m 82p	70 [1]			0.8 [1]		13.9	20.2		
NL	VDL	Citea SLF-120 Electric	80 [1]					10.8	16.0		
NL	VDL	Citea SLFA-180 Electric	80 [1]					7.8	12.0		
SE	Volvo	10.7m						8.6			
SE	Volvo	7900 Electric	80 [1]			0.79 [1]		8.4		26[70]	
CN	Wuzhoulong	FDG6113EVG	80[71]								
CN	YinLong	12m	69[72]								
CN	YinLong	12m	69[72]				150[72]				
CN	Yutong	ZK6105BEVG									
CN	Yutong	E12	85 [1]				320[81]				6.5[74]
CN	Zhong Tong	LCK6122EVG	69[75]				414[82]	8.9			

Table 2.3: Battery specifications of studied battery electric city buses, 10-13m long. (Skywell Nanjing Golden Dragon is abbreviated to Skywell Nan.Gol.Dra.

	Bus Brand	Bus Model	Battery Supplier	Batt. Capac. (kWh)	Batt. Capac. (Ah)	Max. DC Volt. (V)	Batt. Volt. (V)	Batt. Type	Batt. Warr. (yrs)
FR	Alstom NTL	APTIS	Fiamm [1]	346 [1]				NaNiCl2 [1]	
CN	Ankai	HFF6123G03EV-2			600[14]		538[14]		
AU	Avass	Metro Bus Series		259[15]	450[15]		576[15]	LiFePO4[15]	
AU	Avass	Matilda City Bus		254[16]			600[16]	LiFePO4[16]	
FR	Bollore	Bluebus 12m	BlueSolutions [1]	272[76]			410[17]	LiPo[17]	7 [1]
CA	Bombardier, Hess	Primove		60[18]			660[18]		
TR	Bozankaya A.S.	Sileo S10	Bozankaya BC&C [1]	230[19]		700[19]	500[19]	LiFePO4[19]	4 [1]
TR	Bozankaya A.S.	Sileo S12	Bozankaya BC&C [1]	230[20]		700[20]	500[20]	LiFePO4[20]	4 [1]
IT	BredaMenarinibus	Citymood 12 E		240[21]	400[21]				
FR	Businova	Midibus L		350[22]					
CN	BYD	K9		324[23]				LiFePO4[23]	
CN	BYD (Europe)	LE 2 doors					400[77]	LiFePO4[77]	
CN	BYD (SG)	K9	BYD [25]	324[25]			400[25]	LiFePO4[25]	
CN	BYD USA	40"		500[26]				LiFePO4[26]	12[26]
PT	Caetano	e. City Gold		250[27]			700[27]	LiTi, NMC [1]	5 [1]
US	Chariot Motors	12m (Siemens)	Aowei [29]	40[29]		750[29]		Graph. U.Cap. [1]	8 [1]
US	Chariot Motors	12m (ZF)	Aowei [29]	40[29]		750[29]		Graph. U.Cap. [1]	8 [1]
CN	DFAC	EQ6100CACBEV							
DE	ebeEUROPA	Blue City Bus	Samsung [32]	265[32]				NMC[32]	
NL	Ebusco	2.1 LF-311-HV-2/3	Ebusco [1]	311 [1]		700[34]	630[34]	LiFePO4 [1]	
CZ	Ekova	Electron 12m		265[35]					
CN	Golden dragon	XML6125CLE (Ebusco 2.1)		311[36]	50[36]	630[36]	576[36]		
CN	Golden dragon	BEV						LiFePO4[78]	
CA	GreenPower	EV300		260[39]				LiFePO4[39]	
CA	GreenPower	EV350		320[39]				LiFePO4[39]	
CN	Guangtong	GTQ6105BEVBT2			125[40]		580[40]		
CN	Guangtong	GTQ6105BEVB2							
CN	Guangtong	GTQ6105BEVB3			125[40]		580[40]		
CN	Guangtong	GTQ6105BEVBT			396[40]				
CN	Guangtong	GTQ6121BEVB2							
CN	Guangtong	GTQ6121BEVBT			176[40]		576[40]		
CN	Guangtong	GTQ6121BEVBT2			150[40]		580[40]		
FR	Heuliez	GX 337 ELEC	Foresee [1]	349 [1]			400[41]	NMC [1]	
CN	Higer	KLQ6125GEV	Aowei [42]	20[42]			585[42]	U.Cap.[42]	
CN	Hunan CRRC	TEG6125BEV03	Offnenbach [1]	201 [1]				NMC [1]	
CN	Hunan CRRC	TEG6129BEV03	CATL [1]	183 [1]			384[43]	LiFePO4 [1]	
SE	Hybricon	HAW 12 LE						LTO Li Ti[44]	
SE	Hybricon	HAW 12 LF						LTO Li Ti[44]	
SE	Hybricon	HCB 12 LE						Li-ion[44]	
SE	Hybricon	HCB 12 LF						Li-ion[44]	
SE	Hybricon	HCB 12 LF	BMZ [1]	265 [1]				NMC [1]	10 [1]
ES	Irizar	10		329[45]		650[45]	600[45]	NaNiCl2[45]	
ES	Irizar	ie (prev. i2e)	FIAMM [1]	376[45]		650[45]	600[45]	ZEBRA [1]	2 [1]
CN	King Long	XMQ6106G EV						LFP[46]	
CN	King Long	VMQ6111G EV						LFP[46]	
CN	King Long	XMQ6127G EV						LFP[46]	
FI	Linkker Oy	Linkker 12+ LE	Actia IM+E [1]	79 [1]				LTO [1]	10 [1]
DE	Mercedes-Benz	eCitaro		243[49]			400[49]	NMC[83]	
US	New Flyer	35" 11m		400[50]				NMC[50]	
US	New Flyer	40" 12m	XALT Energy, A123	545[79]				NMC[79]	6[52]
GB	Optare	Solo EV standard		138[53]	138[53]		333[53]	LiFeMgPO4[53]	
GB	Optare	Metrocity EV MC 10130	Valence [1]	138 [1]				LiFeMgPO4 [1]	5 [1]
GB	Optare	Metrocity EV MC 10820							
GB	Optare	Metrocity EV MC 11520							
GB	Optare	Versa EV	Valence [1]	138 [1]				LiFeMgPO4 [1]	5 [1]
US	Proterra	Catalyst 35" E2		440[54]					12[54]
US	Proterra	Catalyst 35" FC		94[54]					12[54]
US	Proterra	Catalyst 35" FC+		126[54]					12[54]
US	Proterra	Catalyst 35" XR		220[54]					12[54]
US	Proterra	Catalyst 35" XR+		330[54]					12[54]
US	Proterra	Catalyst 40" FC		94[55]					12[55]
US	Proterra	Catalyst 40" E2		440[55]					12[55]
US	Proterra	Catalyst 40" E2 max		660[55]					12[55]
US	Proterra	Catalyst 40" E2+		550[55]					12[55]
US	Proterra	Catalyst 40" FC+		126[55]					12[55]
US	Proterra	Catalyst 40" XR		220[55]					12[55]
US	Proterra	Catalyst 40" XR+		330[55]					12[55]
IT	Rampini	E120	Winston battery [1]	240[56]	400[56]			LFP [1]	2 [1]
CZ	ŠKODA	ŠKODA Perun HE	[1]	222[80]			600[80]	LiFePO4 [1]	4 [1]
CZ	ŠKODA	ŠKODA Perun HP	[1]	78[59]			650[59]	LiFePO4 [1]	4 [1]
CN	Skywell Nan.Gol.Dra.	NJL6100BEV30							
CN	Skywell Nan.Gol.Dra.	NJL6100BEV36	Hefei Guoxuan Gaoke[61]		300[61]				
CN	Skywell Nan.Gol.Dra.	NJL6100BEV39							
CN	Skywell Nan.Gol.Dra.	NJL6100BEV43							
PL	Solaris	Urbino 12 electric	Solaris [1]	240 [1]				LiFePO4/LTO [1]	10 [1]
CZ	SOR	SOR EBN 11	Winston Battery [1]	172 [1]				Li [1]	
CZ	SOR	NS 12 electric		225[63]	362[63]		600[63]	NMC[63]	
TR	TEMSA	Temsa Avenue EV	Microvast [1]	75 [1]				LiTi [1]	2 [1]
SK	Troliga	Leonis Electric		291[66]					
PL	URSUS	City Smile 9.95m	EVC [1]	210 [1]				LiFePO4 [1]	5 [1]
PL	URSUS	Ekovolt E70110	Impact [1]	120 [1]		750[84]	500[67]	LiFePO4 [1]	5 [1]
PL	URSUS	City Smile 12m 62p	Hybricon Bus [1]	105 [1]				LiTi [1]	15 [1]
PL	URSUS	City Smile 12m 82p	Impact [1]	175 [1]		750[84]		LiFePO4 [1]	5 [1]
NL	VDL	Citea SLF-120 Electric	[1]	180[85]				Li [1]	
NL	VDL	Citea SLFA-180 Electric	[1]	288[85]			650[68]	Li [1]	
SE	Volvo	10.7m		76[69]			600[69]		
SE	Volvo	7900 Electric	SAFT [1]	76 [1]			600[70]	LiFePO4 [1]	
CN	Wuzhoulong	FDG6113EVG							
CN	YinLong	12m			300[72]		580[72]	LFP[72]	
CN	YinLong	12m			300[72]		576[72]	LFP[72]	
CN	Yutong	ZK6105BEVG							
CN	Yutong	E12	CATL [1]	295[74]				LiFePO4 [1]	
CN	Zhong Tong	LCK6122EVG		230[75]	240[75]		540[75]	LiFePO4[75]	

Table 2.4: Electric motor specifications of studied battery electric city buses, 10-13m long, **table 1 of 2**. (Skywell Nanjing Golden Dragon is abbreviated to Skywell Nan.Gol.Dra. and Wuhan Ligong Tongyu is abbreviated to Wuhan Lig.Ton.)

	Bus Brand	Bus Model	Motor Supplier	Motor Model	Motor Type	Speed at max. power (rpm)	Max. speed (rpm)
FR	Alstom NTL	APTIS	Alstom [1]		PM [1]		
CN	Ankai	HFF6123G03EV-2	Ankai[14]				
AU	Avass	Metro Bus Series			PMSM[15]		
AU	Avass	Matilda City Bus			PMSM[16]		
FR	Bollore	Bluebus 12m	Siemens [1]	1DB2016 WS54[86]	PMSM[17]	600[86]	3 500[86]
CA	Bombardier, Hess	Primove					
TR	Bozankaya A.S.	Sileo S10	ZF[19]	AVE 130[19]	IM[87]		11 000[87]
TR	Bozankaya A.S.	Sileo S12	ZF[20]	AVE 130[20]	IM[87]		11 000[87]
IT	BredaMenarinibus	Citymood 12 E	Siemens[21]	1DB2016[21]	PMSM[21]	600[86]	3 500[86]
FR	Businova	Midibus L			PM[22]		
CN	BYD	K9	BYD [1]	TYC-90A[88]	PMSM[23]		7 500[23]
CN	BYD (Europe)	LE 2 doors	BYD [1]	TYC-150A[88]	PMSM[77]		10 000[77]
CN	BYD (SG)	K9	BYD [1]	TYC-150A[88]	PMSM[77]		10 000[77]
CN	BYD USA	40"	BYD [1]	TYC-150A[88]	PMSM[77]		10 000[77]
PT	Caetano	e. City Gold	Siemens [1]	1DB2016 WS54[86]	PMSM[86]	600[86]	3 500[28]
US	Chariot Motors	12m (Siemens)	Siemens[29]	1DB2016 1-wind[89]	PMSM[29]		3 500[89]
US	Chariot Motors	12m (ZF)	ZF[29]	AVE 130[29]	IM[87]		11000[87]
CN	DFAC	EQ6100CACBEV	Hunan CRRC[30]		PMSM[30]		
DE	ebeEUROPA	Blue City Bus	Ziehl-Abegg[32]	SM530[32]	PMSM[90]		485[32]
NL	Ebusco	2.1 LF-311-HV-2/3	Ebusco [1]		IM [1]	1050[34]	3 000[34]
CZ	Ekova	Electron 12m	Ziehl-Abegg[35]	V1.0[90]	PMSM[90]		485[91]
CN	Golden dragon	XML6125CLE (Ebusco 2.1)				1000[36]	
CN	Golden dragon	BEV			PMSM[78]		
CA	GreenPower	EV300	Siemens[39]				
CA	GreenPower	EV350	Siemens[39]	1PV5138-4WS24[86]	IM[86]	3000[86]	10 000[86]
CN	Guangtong	GTQ6105BEVBT2		YTP MPl 20 W[40]			
CN	Guangtong	GTQ6105BEVB2		YTP MPl 20 W[40]			
CN	Guangtong	GTQ6105BEVB3		YTP MPl 20 W[40]			
CN	Guangtong	GTQ6105BEVBT		KAM280HF[40]			
CN	Guangtong	GTQ6121BEVB2	Zhuhai Yintong[40]	WP6NG210E50[40]			
CN	Guangtong	GTQ6121BEVBT		YTP MP]50 W[40]			
CN	Guangtong	GTQ6121BEVBT2		YTP MP150 W[40]			
FR	Heuliez	GX 337 ELEC	BAE Systems [1]		PM [1]		
CN	Higer	KLQ6125GEV	Siemens[42]	IPV5135 4WS28[42]	IM[86]	2700[86]	10 000[86]
CN	Hunan CRRC	TEG6125BEV03	Hunan CRRC [1]		PMSM [1]		
CN	Hunan CRRC	TEG6129BEV03	Hunan CRRC [1]	JD156 [1]	PMSM [1]		
SE	Hybricon	HAW 12 LE	Ziehl-Abegg[44]	SM530 whl[90]	PMSM[90]		485[91]
SE	Hybricon	HAW 12 LF	Ziehl-Abegg[44]	SM530 whl[90]	PMSM[90]		485[91]
SE	Hybricon	HCB 12 LE	Ziehl-Abegg[44]	SM530 whl[90]	PMSM[90]		485[91]
SE	Hybricon	HCB 12 LF	Ziehl-Abegg[44]	SM530 whl[90]	PMSM[90]		485[91]
SE	Hybricon	HCB 12 LF	Ziehl-Abegg [1]	SM530.60AL-30 whl [1]			
ES	Irizar	10	Siemens[45]	1DB2016 WS54[86]	PMSM[86]	600[86]	3 500[86]
ES	Irizar	ie (prev. i2e)	Siemens [1]	1DB2016 WS54[86]	PMSM[86]	600[86]	3 500[86]
CN	King Long	XMQ6106G EV					
CN	King Long	VMQ6111G EV					
CN	King Long	XMQ6127G EV					
FI	Linkker Oy	Linkker 12+ LE	Visedo [1]		PM [1]		
DE	Mercedes-Benz	eCitaro	ZF[49]	AVE 130[49]	IM[87]		11 000[49]
US	New Flyer	35" 11m	Siemens[50]	1DB2022[50]	PMSM[86]	600[86]	3 500[86]
US	New Flyer	40" 12m	Siemens[79]	1DB2022[79]	PMSM[86]	600[86]	3 500[86]
GB	Optare	Solo EV standard			PM[53]		
GB	Optare	Metrocity EV MC 10130	Magtec [1]		PM[53]		
GB	Optare	Metrocity EV MC 10820			PM[53]		
GB	Optare	Metrocity EV MC 11520			PM[53]		
GB	Optare	Versa EV	Magtec [1]		PM[53]		
US	Proterra	Catalyst 35" E2			PM[54]		
US	Proterra	Catalyst 35" FC			PM[54]		
US	Proterra	Catalyst 35" FC+			PM[54]		
US	Proterra	Catalyst 35" XR			PM[54]		
US	Proterra	Catalyst 35" XR+			PM[54]		
US	Proterra	Catalyst 40" FC			PM[55]		
US	Proterra	Catalyst 40" E2			PM[55]		
US	Proterra	Catalyst 40" E2 max			PM[55]		
US	Proterra	Catalyst 40" E2+			PM[55]		
US	Proterra	Catalyst 40" FC+			PM[55]		
US	Proterra	Catalyst 40" XR			PM[55]		
US	Proterra	Catalyst 40" XR+			PM[55]		
IT	Rampini	E120	Siemens [1]	1DB2016[56]	PMSM[86]	600[86]	3 500[86]
CZ	ŠKODA	ŠKODA Perun HE	ŠKODA [1]		IM[58]		
CZ	ŠKODA	ŠKODA Perun HP	ŠKODA[59]		IM[59]		
CN	Skywell Nan.Gol.Dra.	NJL6100BEV30					
CN	Skywell Nan.Gol.Dra.	NJL6100BEV36					
CN	Skywell Nan.Gol.Dra.	NJL6100BEV39					
CN	Skywell Nan.Gol.Dra.	NJL6100BEV43					
PL	Solaris	Urbino 12 electric	TSA, ZF [1]	AVE 130[87]	IM [1]		11 000[87]
CZ	SOR	SOR EBN 11	Pragoimex [1]		IM [1]		
CZ	SOR	NS 12 electric	Pragoimex[63]		IM[63]		
TR	TEMSA	Temsa Avenue EV	TM4 [1]	HV2700-9P[84]	PM [1]		3 375[84]
SK	Troliga	Leonis Electric	Ziehl-Abegg[66]	SM530.60AL-30[66]	PMSM[90]		485[91]
PL	URSUS	City Smile 9.95m	TAM [1]	1052C6B [1]	IM[92]		
PL	URSUS	Ekovolt E70110	TM4 [1]	LSM280AHV-3400A1 [1]	PMSM[84]		2 450[84]
PL	URSUS	City Smile 12m 62p	Ziehl-Abegg [1]	530.60AL-30 [1]	PMSM[90]		485[91]
PL	URSUS	City Smile 12m 82p	TM4 [1]	LSM280AHV-3400A1 [1]	PMSM[84]		2 450[84]
NL	VDL	Citea SLF-120 Electric	Siemens[68]	1DB2016[68]	PMSM[86]	600[86]	3 500[86]
NL	VDL	Citea SLFA-180 Electric	Siemens[68]	1DB2016[68]	PMSM[86]	600[86]	3 500[86]
SE	Volvo	10.7m					
SE	Volvo	7900 Electric	In motion [1]		PM [1]		
CN	Wuzhoulong	FDG6113EVG		YPQ220M-6[71]			
CN	YinLong	12m					
CN	YinLong	12m					
CN	Yutong	ZK6105BEVG					
CN	Yutong	E12	Yutong[74]	YTM280-CV4-H[74]	PMSM[74]		
CN	Zhong Tong	LCK6122EVG	Wuhan Lig.Ton.[75]	WTEM80-40-2[75]			

Table 2.5: Electric motor specifications of studied battery electric city buses, 10-13m long, **table 2 of 2**. (Skywell Nanjing Golden Dragon is abbreviated to Skywell Nan.Gol.Dra.

	Bus Brand	Bus Model	No. EMs		Peak Pow. per EM (kW)	Cont. Pow. per EM (kW)	Max. Torq. per EM (Nm)	Nom. Torq. per EM (Nm)	Total Max. EM Torq. (Nm)	Total EM Peak Pow. (kW)	Total Cont. Pow. (kW)
FR	Alstom NTL	APTIS							180 [1]	970 [1]	
CN	Ankai	HFF6123G03EV-2									
AU	Avass	Metro Bus Series							2400[15]	200[15]	
AU	Avass	Matilda City Bus								180[16]	
FR	Bollore	Bluebus 12m	1		160[86]	160[86]	2500[86]	1500[86]	2500 [1]	160 [1]	160[86]
CA	Bombardier, Hess	Primove	2	[18]	140[18]	60[18]				280[18]	120[18]
TR	Bozankaya A.S.	Sileo S10	2	[19]	125[87]	60[87]	485[87]	180[87]	970[87]	250[87]	120[87]
TR	Bozankaya A.S.	Sileo S12	2	[20]	125[87]	60[87]	485[87]	180[87]	970[87]	250[87]	120[87]
IT	BredaMenarinibus	Citymood 12 E	1		160[21]	160[86]	2500[21]	1500[86]	2500[21]	160[21]	160[86]
FR	Businova	Midibus L								250[22]	
CN	BYD	K9	2	[23]	90[23]	75[23]	350[23]		700[23]	180[23]	150[23]
CN	BYD (Europe)	LE 2 doors	2	[24]	150[24]		550[77]		1100[77]	300[77]	
CN	BYD (SG)	K9	2	[25]	150[25]		550[25]		1100[25]	300[25]	
CN	BYD USA	40"	2	[26]	150[26]		550[26]		1100[26]	300[26]	
PT	Caetano	e. City Gold	1		160[86]	160[86]	1500[86]	1500[28]	2500[28]	160[86]	160[28]
US	Chariot Motors	12m (Siemens)	1					891[29]	2800[29]	180[29]	140[29]
US	Chariot Motors	12m (ZF)	2	[29]	125[29]	60[87]	485[87]	180[87]	970[87]	250[29]	120[87]
CN	DFAC	EQ6100CACBEV								150[30]	100[30]
DE	ebeEUROPA	Blue City Bus	2		182[91]	113[32]	6000[91]	2700[32]	12000[91]	364[91]	226[91]
NL	Ebusco	2.1 LF-311-HV-2/3	1	[33]				1000[34]	3000 [1]	220 [1]	110[34]
CZ	Ekova	Electron 12m	2	[35]	182[91]	113[35]	6000[91]	2700[91]	12000[91]	364[91]	226[35]
CN	Golden dragon	XML6125CLE (Ebusco 2.1)							2500[36]	150[36]	
CN	Golden dragon	BEV									
CA	GreenPower	EV300									
CA	GreenPower	EV350	2	[38]	150[86]	85[86]	530[86]	220[86]	1000[38]	300[38]	170[86]
CN	Guangtong	GTQ6105BEVBT2									
CN	Guangtong	GTQ6105BEVB2									
CN	Guangtong	GTQ6105BEVB3									
CN	Guangtong	GTQ6105BEVBT									
CN	Guangtong	GTQ6121BEVB2								155[40]	
CN	Guangtong	GTQ6121BEVBT									
CN	Guangtong	GTQ6121BEVBT2									
FR	Heuliez	GX 337 ELEC			190 [1]	120 [1]	3300 [1]	1610 [1]	3300 [1]	190 [1]	
CN	Higer	KLQ6125GEV			120[86]	67[86]	430[86]	160[86]	430[86]	120[86]	67[86]
CN	Hunan CRRC	TEG6125BEV03							2500 [1]	150 [1]	
CN	Hunan CRRC	TEG6129BEV03							2500 [1]	150 [1]	100[43]
SE	Hybricon	HAW 12 LE	2	[44]	182[44]	113[44]	5900[44]	3200[44]	11800[44]	364[44]	226[44]
SE	Hybricon	HAW 12 LF	2	[44]	182[44]	113[44]	5900[44]	3200[44]	11800[44]	364[44]	226[44]
SE	Hybricon	HCB 12 LE	2	[44]	182[44]	113[44]	5900[44]	3200[44]	11800[44]	364[44]	226[44]
SE	Hybricon	HCB 12 LF	4	[44]	182[44]	113[44]	5900[44]	3200[44]	23600[44]	728[44]	226[44]
SE	Hybricon	HCB 12 LF	2	[1]	157 [1]		6000 [1]	2100 [1]	12000 [1]	314 [1]	
ES	Irizar	10	1		160[86]	160[86]	2500[86]	1500[45]	2500[86]	160[86]	160[45]
ES	Irizar	ie (prev. i2e)	1		160[86]	160[86]	2500[86]	1400[45]	2500[86]	160[86]	180[45]
CN	King Long	XMQ6106G EV								200[46]	100[46]
CN	King Long	VMQ6111G EV								200[46]	100[46]
CN	King Long	XMQ6127G EV								200[46]	100[46]
FI	Linkker Oy	Linkker 12+ LE							7824[47]	180 [1]	
DE	Mercedes-Benz	eCitaro	2	[49]	125[49]	60[87]	485[49]	180[87]	970[87]	250[49]	120[87]
US	New Flyer	35" 11m	1		240[86]	200[86]	3800[86]	2000[86]	3800[86]	240[86]	200[86]
US	New Flyer	40" 12m	1		240[86]	200[86]	3800[86]	2000[86]	3800[86]	240[86]	200[86]
GB	Optare	Solo EV standard							3168[53]	220[53]	
GB	Optare	Metrocity EV MC 10130							3168[53]	220[53]	
GB	Optare	Metrocity EV MC 10820							3168[53]	220[53]	
GB	Optare	Metrocity EV MC 11520							3168[53]	220[53]	
GB	Optare	Versa EV							3168[53]	220[53]	
US	Proterra	Catalyst 35" E2								380[54]	191.6[54]
US	Proterra	Catalyst 35" FC								269[54]	167.8[54]
US	Proterra	Catalyst 35" FC+								380[54]	191.6[54]
US	Proterra	Catalyst 35" XR								179[54]	111.9[54]
US	Proterra	Catalyst 35" XR+								269[54]	167.8[54]
US	Proterra	Catalyst 40" FC								269[55]	167.8[55]
US	Proterra	Catalyst 40" E2								380[55]	191.6[55]
US	Proterra	Catalyst 40" E2 max								380[55]	191.6[55]
US	Proterra	Catalyst 40" E2+								380[55]	191.6[55]
US	Proterra	Catalyst 40" FC+								380[55]	191.6[55]
US	Proterra	Catalyst 40" XR								179[55]	111.9[55]
US	Proterra	Catalyst 40" XR+								269[55]	167.8[55]
IT	Rampini	E120	1	[56]	160[86]	160[86]	2500[86]	1500[86]	2500[86]	160[56]	160[86]
CZ	ŠKODA	ŠKODA Perun HE	1	[58]					1800 [1]	160 [1]	
CZ	ŠKODA	ŠKODA Perun HP	1	[59]					1800 [1]	160 [1]	
CN	Skywell Nan.Gol.Dra.	NJL6100BEV30									
CN	Skywell Nan.Gol.Dra.	NJL6100BEV36								100[61]	
CN	Skywell Nan.Gol.Dra.	NJL6100BEV39									
CN	Skywell Nan.Gol.Dra.	NJL6100BEV43									
PL	Solaris	Urbino 12 electric	2	[1]	125 [1]	60 [1]	485[87]	180[87]	970[87]	250[87]	120[87]
CZ	SOR	SOR EBN 11							968 [1]	120 [1]	
CZ	SOR	NS 12 electric								160[63]	
TR	TEMSA	Avenue EV	1	[65]	250[84]	195[84]	2700[84]	2060[84]	2700[65]	250[65]	195[84]
SK	Troliga	Leonis Electric	2	[66]	182[91]	113[66]	6000[91]	2700[91]	12000[91]	364[91]	226[66]
PL	URSUS	City Smile 9.95m	1	[92]					835 [1]	120 [1]	
PL	URSUS	Ekovolt E70110	1		250[84]	170[84]	3400[84]	1600[84]	3400[84]	250[84]	170 [1]
PL	URSUS	City Smile 12m 62p	2	[67]	182[91]	110[67]	6000[91]	2700[91]	12000[91]	364[91]	226 [1]
PL	URSUS	City Smile 12m 82p	1		250[84]	170[84]	3400[84]	1600[84]	3400[84]	250[84]	170 [1]
NL	VDL	Citea SLF-120 Electric	1		160[86]	160[86]	2500[86]	1500[68]	2500 [1]	160[86]	153[68]
NL	VDL	Citea SLFA-180 Electric	1		160[86]	160[86]	2500[86]	1500[68]	2500 [1]	153 [1]	153[68]
SE	Volvo	10.7m							400[69]	155[69]	
SE	Volvo	7900 Electric							400[70]	160[70]	
CN	Wuzhoulong	FDG6113EVG									
CN	YinLong	12m									
CN	YinLong	12m									
CN	Yutong	ZK6105BEVG									
CN	Yutong	E12							2400[74]	200[74]	
CN	Zhong Tong	LCK6122EVG						477[75]	1000[75]	160[75]	80[75]

2.3.1 Electric Motor Supplier, Model and Type

In total, the specifications for 146 BECB models are listed in this report; 93 are 10-13m, 53 are shorter or longer. Electric motor manufacturer data was found for 89 (61%)of the BECB models, motor model for 69 (47%), and motor type for 98 (67%) of them.

The number of BEV bus models per electric motor supplier, of all the found city buses (including the ones in Appendix C), is presented in Figure 2.7. The five most frequent are:

1. Siemens - 27.9%
2. Ziehl-Abegg - 15.1%
3. ZF - 9.3%
4. TM4 - 8.1%
5. BYD - 5.8%

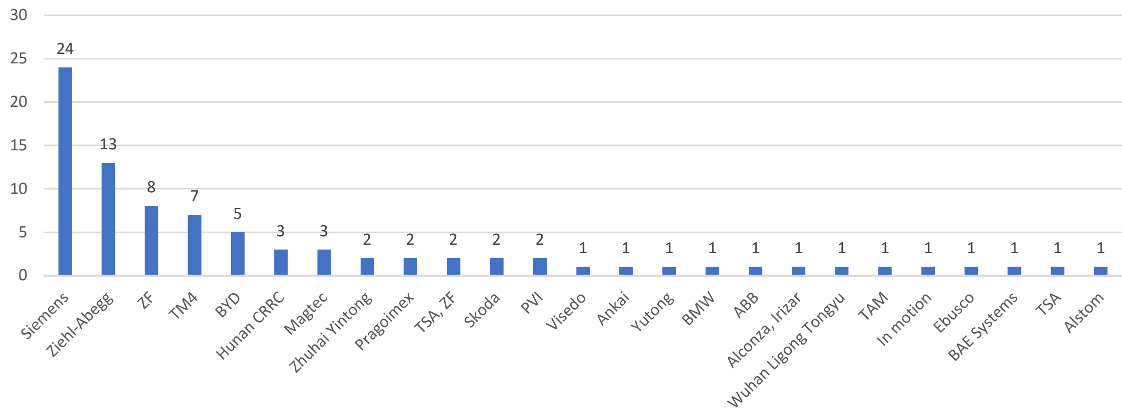


Figure 2.7: The number of BEV bus models per electric motor supplier, from Table 2.4 and Table C.2 in Appendix C.

The number of BEV bus models per electric motor model, of all the found city buses (including the ones in Appendix C), is presented in Figure 2.8. Motor model has been found for 69 of the buses. The top five models are:

1. Siemens, 1DB2016 (PMSM) - 20.3%
2. Ziehl-Abegg, SM530 (PMSM, in-wheel) - 17.4%
3. ZF, AVE130 (IM) - 15.9%
4. Siemens, 1DB2022 (PMSM) - 7.2%
5. BYD, TYC-150A (PMSM, wheel hub)- 5.8%
6. TM4, LSM280A HV-3400 (PMSM) - 5.8%

Unfortunately, little data has been found regarding Chinese electric motor manufacturers. Perhaps Chinese language skills would have helped.

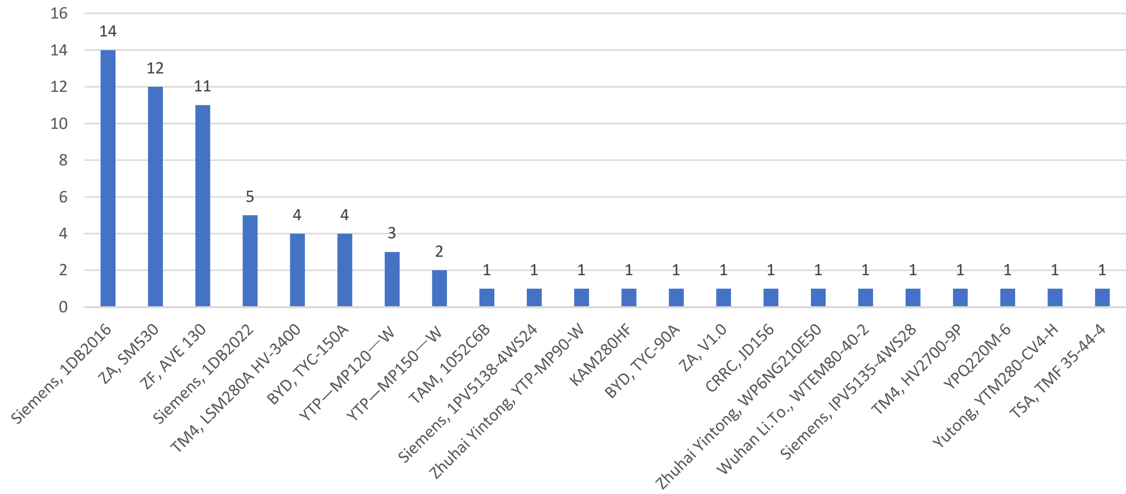


Figure 2.8: The number of BEV bus models per electric motor model and supplier, from Table 2.4 and Table C.2 in Appendix C.

As a reference, data collected and presented by Stefan Baguette (Market Analyst and Product Manager at Alexander Dennis Limited, ADL), regarding the market share per electric system suppliers to electric bus manufacturers in Europe at the end of 2017 is presented in Figure 2.1 [6].

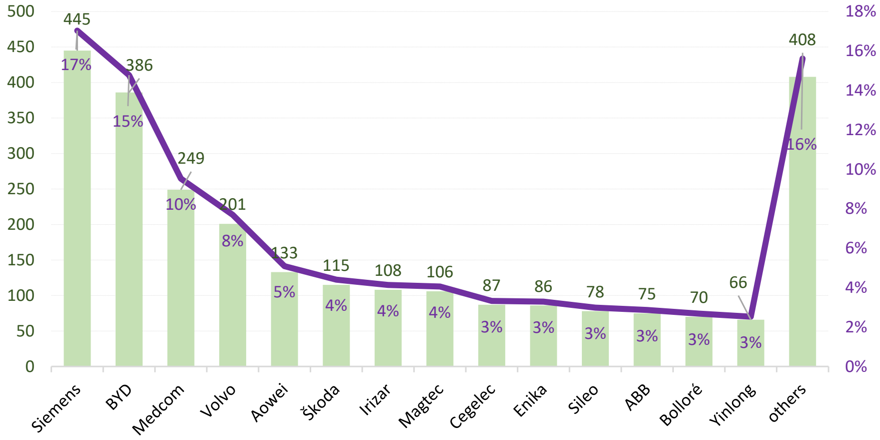


Figure 2.9: Electric system suppliers for electric buses in Europe, at end of 2017 [6]. Left axis: units sold, right axis: market share.

The number of BEV bus models per electric motor type, of all the found city buses (including the ones in Appendix C), is presented in Figure 2.10. Motor type has been found for 98 of the buses. Over 75% of the motors are PM machines, about 24.5% are IM's (Induction Machines). It is likely that machines stated as "PM" are infact also PMSMs.

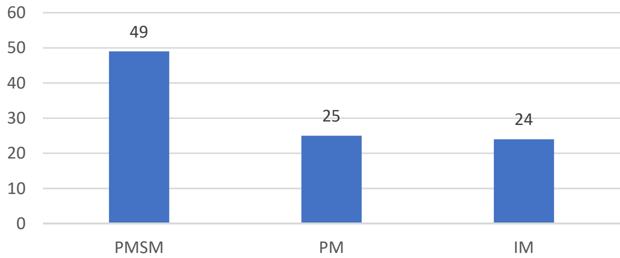


Figure 2.10: The number of BEV bus models per electric motor model and supplier, from Table 2.4 and Table C.2 in Appendix C.

2.3.2 Electric Motor Supplier Data

Electric motor specification data was found for some of the suppliers. Table 2.6 and Table 2.7 show a summary of specifications for some of the used electric motor models, where data could be found.

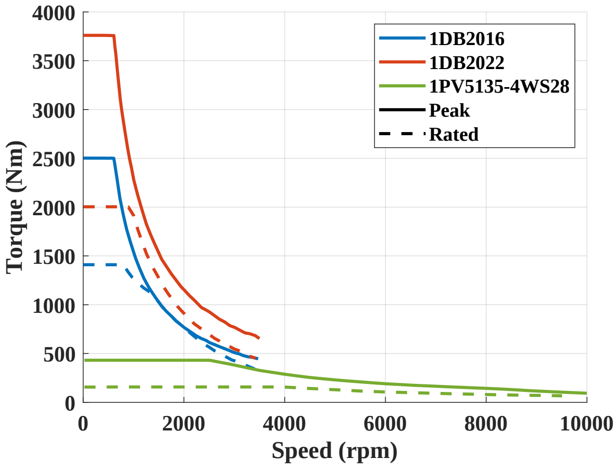
Table 2.6: Electric motor specifications for some of the used motor models, for 10-13m long battery electric city buses, **table 1 of 2**

Brand	Model	Type	Phases	Rated DC Voltage (V)	Max current (A)	Rated Current (A)	I_{max}/I_{rated}	Weight (kg)	Length (mm)	Width (mm)	Height (mm)
Siemens	1PV5135-4WS28	IM [86]	3	650[86]	300[86]	124[86]	2.4	90[86]	425[86]	245[86]	245[86]
Siemens	1PV5138-4WS24	IM [86]	3	650[86]	300[86]	142[86]	2.1	120[86]	510[86]	245[86]	245[86]
Siemens	1DB2016–WS54	PMSM[86]	3[86]	650[86]	350[86]	210[86]	1.7	350[86]	510[86]	510[86]	500[86]
Siemens	1DB2022–WS36	PMSM[86]	6[86]	650[86]	600[86]	320[86]	1.9	480[86]	620[86]	510[86]	500[86]
Siemens	1DB2016 1-wind (2018)		3[89]	650[89]							
ZF	AVE 130	IM [87]	3[87]	650[87]	340[87]	250[87]	1.4				
ZiehlAbegg	Zawheel, V1.0	PMSM[90]		625[93]		230[93]					
ZiehlAbegg	Zawheel, 2nd gen	PMSM[90]		600[90]		200[90]					
TM4	HV2700-9P	PMSM[94]	9[94]	600[94]	350[95]			340[94]	505[94]	572[94]	
TM4	LSM280A HV-3400	PMSM[96]	9[96]	750[96]	350[95]			336[96]	514[96]		
TSA	TMF 35-44-4			420[97]	269[97]			480[97]			
Ebusco		IM [33]	3[34]	380[34]	500[34]	250[34]	2.0	496[34]	636[34]	510[34]	
WuhanPNSP	WTEM80-38-1	IM [98]	3[98]	380[98]	290[98]	145[98]	2.0				
WuhanPNSP	WTEMT100/4-08/4-0	IM [98]	3[98]	380[98]	290[98]	145[98]	2.0				
BYD	TYC-90A wheel	PMSM[99]		540[99]							
BYD	TYC-150A wheel	PMSM[99]									
BYD	TYC-180A wheel	PMSM[99]									

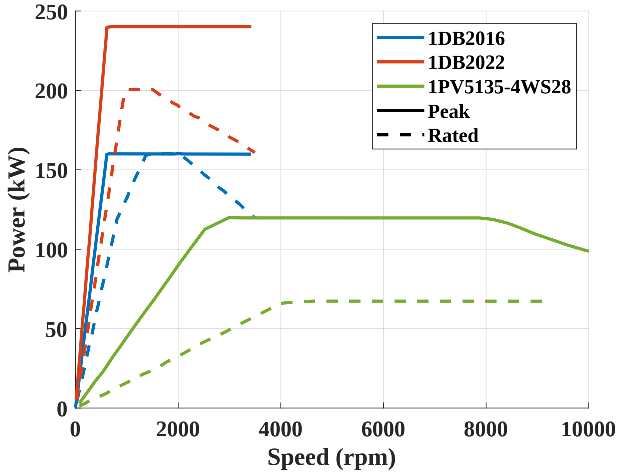
Table 2.7: Electric motor specifications for some of the used motor models, for 10-13m long battery electric city buses, **table 2 of 2**

Brand	Model	Max Power (kW)	Rated Power (kW)	P_{max}/P_{rated}	Max Torque (Nm)	Rated Torque (Nm)	T_{max}/T_{rated}	P_{max}/mass (W/kg)	Max Speed (rpm)	Base Speed at T_{rated} (rpm)	Base Speed at T_{max} (rpm)	Max/base speed
Siemens	1PV5135-4WS28	120[86]	67[86]	1.8	430[86]	160[86]	2.7	1.33	10 000[86]	4000[86]	2500[86]	
Siemens	1PV5138-4WS24	150[86]	85[86]	1.8	530[86]	220[86]	2.4	1.25	10 000[86]	3500[86]	3000[86]	
Siemens	1DB2016 – WS54	160[86]	160[86]	1.0	2500[86]	1500[86]	1.7	0.46	3 500[86]	800[86]	600[86]	4.4
Siemens	1DB2022 – WS36	240[86]	200[86]	1.2	3800[86]	2000[86]	1.9	0.50	3 500[86]	1000[86]	600[86]	3.5
Siemens	1DB2016 1-wind (2018)	180[89]	140[89]		2500[89]	891[89]			3 500[89]			
ZF	AVE 130	125[87]	60[87]	2.1	485[87]	180[87]	2.7		11 000[87]			
Ziehl Abegg	Zawheel, V1.0		120[93]			3700[93]			500[93]			
Ziehl Abegg	Zawheel, 2nd gen	182[91]	113[90]	1.6	6000[91]	2 700[90]	2.2		485[91]			
TM4	HV2700-9P	250[94]	195[94]	1.3	2700[94]	2 060[94]	1.3	0.74	3 375[94]			
TM4	LSM280A HV-3400	250[96]	170[96]	1.5	3400[96]	1 600[96]	2.1	0.74	2 450[96]			
TSA	TMF 35-44-4	160[97]			1401[97]			0.33	4 466[97]		1477[97]	
Ebusco		220[34]	110[34]	2.0	3000[34]	1000[34]	3.0	0.44	3 000[34]	1050[34]		2.9
Wuhan	PNSPWTEM80-38-1	160[98]	80[98]	2.0	1272[98]	636[98]	2.0		2 600[98]	1200[98]		2.2
Wuhan	PNSPWTEMT100/4-08/4-0	160[98]	80[98]	2.0	954[98]	477[98]	2.0		3 200[98]	1600[98]		2.0
BYD	TYC-90A wheel	90[88]			350[88]				7 500[99]			
BYD	TYC-150A wheel	150[88]			550[88]							
BYD	TYC-180A wheel	180[88]			1500[88]							

For a few of the electric motors used in commercial battery electric city buses, the torque and speed as a function of speed has been found from the manufacturer. As an example, such curves are shown in Figure 2.11 for three Siemens motors.



(a) Total.



(b) Per electric machine.

Figure 2.11: Electric machine peak and rated torque and power curves as a function of speed for three Siemens motors used in commercial battery electric city buses [86].

Chapter 3

Requirements on the Reference Electric Machine for a Battery Electric City Bus

In this chapter, all specification parameters needed for the electric city bus's reference machine are derived, including the specifications for the bus itself. The base for these parameters are the collected specification parameters from the commercial battery electric buses in the previous chapter, mainly from manufacturer data. The selected parameters are then summarized in Table 3.4.

3.1 Bus Dynamics

The force that has to come to the shaft of the driving wheel from the drive system, F_{wheel}, must cover the sum of the aerodynamic drag, rolling resistance, acceleration demand and possible contribution of gravity due to road grade, as in

$$F_{wheel} = \frac{1}{2}\,\rho\,C_d\,A\,v^2 + C_r\,m\,g\,cos(\alpha) + \delta\,m\,\frac{dv}{dt} + m\,g\,sin(\alpha) \tag{3.1}$$

where ρ is the air density (1.2 kg/m^3), C_d is the bus' aerodynamic coefficient, A (m^2) the bus' effective frontal area, v (m^2) the bus speed, C_r the rolling resistance coefficient for the bus tires on the road, δ (1.1) the correction coefficient due to rotating mass, m (kg) the bus weight (curb weight when unloaded, and gross weight when fully loaded), g the earth's gravitational constant (9.81 m/s^2), and α (rad) the road inclination angle towards the horizontal plane.

All of these parameters will be carefully chosen, as to represent a typical battery electric city bus (BECB). The selection process is described in this chapter.

The correction coefficient of the rotating mass, δ, represent the inertia of all rotating parts, such as gears, tires, axles, and electric machine rotors etc. Since most found references presented in Table 3.1, only include the tiers when calculating δ, it can be assumed that the tires stand for the largest contribution to the rotating mass. In some cases, δ is said to depend on the gear ratio. As a simplification, in some found references, δ is approximated as fixed value. Based on the found data, and due to simplicity, δ **is set to 1.1 for the reference BECB**.

Table 3.1: Found estimations of rotating mass correction coefficient, δ, where m is the bus mass, J_{wheel} is the tire inertia, and r_{wheel} is its radius.

Vehicle Type	**Vehicle Weight (kg)** curb/gross	**Rotating mass correction coefficient, δ**	**Ref.**
Plug-in hybrid electric bus	16 500	1.03	[100]
Plug-in hybrid electric city bus	12 600	1.05	[101]
Electric coach bus	16 000 gross	1.1	[102]
Plug-in hybrid electric bus	12 500	1.1	[103]
Electric vehicle (light duty)	1480 curb	1.11	[104]
Series-parallel hybrid electric bus	15 000 gross, 11 500 curb	f(gear ratio), 1.1-1.4	[105]
Vehicles		$1+\frac{1}{m}\frac{\sum J_{wheel}}{r_{wheel}^2}$, f(gear ratio) 1.05-1.6	[106]
Electric bus (Anhui Ankai)	14 500	$1+\frac{1}{m}\frac{\sum J_{wheel}}{r_{wheel}^2}$	[107]
Diesel trailer		$1+\frac{1}{m}\frac{\sum J_{wheel}}{r_{wheel}^2}+J_{flywheel}$	[108]

3.2 Bus Dimensions

Bus dimensions include its length, weight, front area, C_d, C_r and wheel radius.

3.2.1 Length

The vast majority of sold electric buses in Europe are about 12 m long 2.2.3. This is also the dominating length of the studied commercial electric city bus models, as shown in Figure 3.1 including bus data in Appendix C (i.e. including all found battery electric city buses regardless of length). It is therefore chosen that the concept bus should have the length **12 m**.

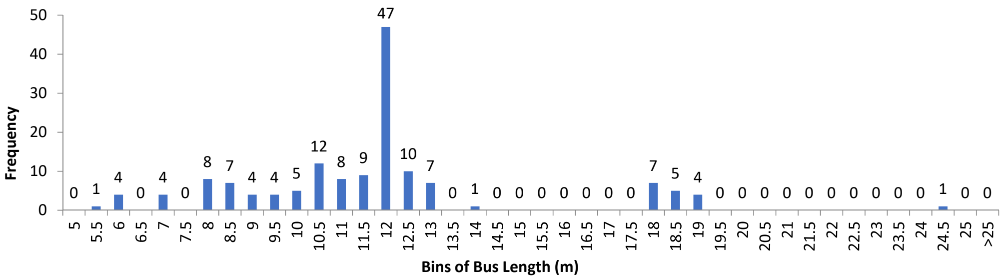


Figure 3.1: Histogram for bus lengths of of commercial battery electric city buses.

3.2.2 Weight

The curb and gross weight versus bus length of 10-13m commercial electric city bus models are presented in Figure 3.2, along with linear-fit lines of weight as a function of length. The curb weight is the bus weight without passengers, and the gross vehicle weight (GVW) is the max. allowed vehicle weight. For the 12m buses there is a spread of around 1000 kg, in both curb and gross weight, depending on build and battery capacity etc. This spread is illustrated in Figure 3.3 as histograms of the curb and gross weight, only for buses that are 12m $\pm$ 0.1m.

For a 12m bus, the linear-fit in Figure 3.2, suggests a curb weight of 13 047 kg, and a gross weight of 18 409 kg. The average curb weight between the 12$\pm$0.1m buses is 12 940 kg, and the average gross weight 18 537 kg.

The concept bus is therefore decided to have a curb weight of **13 000 kg**, and a gross weight of **18 400 kg**.

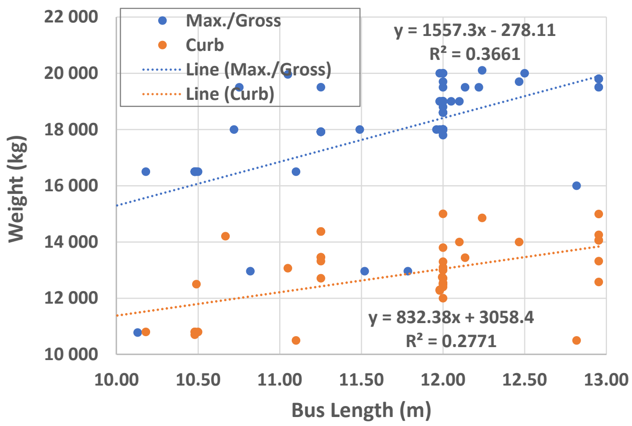
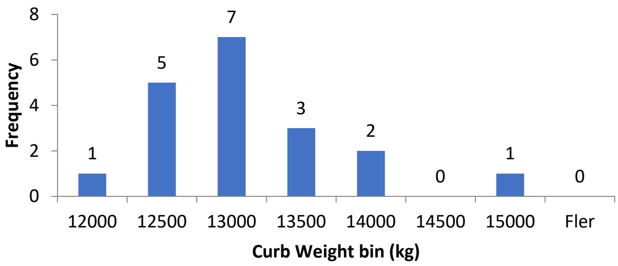
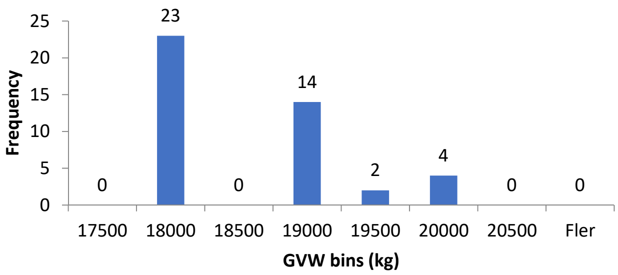


Figure 3.2: Curb weight and gross weight vs. bus length of commercial battery electric city buses 10-13m, along with linear curve fitting.



(a) Curb weight.

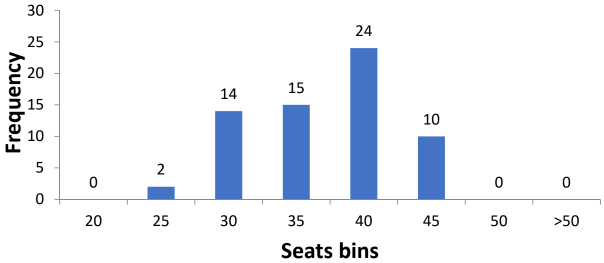


(b) Gross weight.

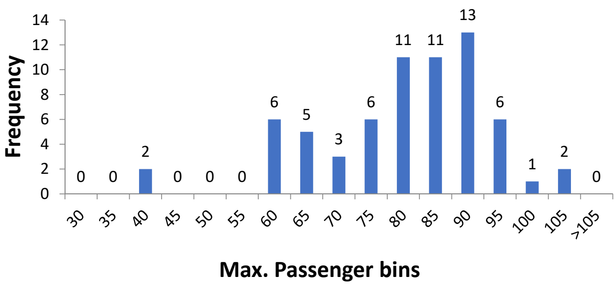
Figure 3.3: Histogram for bus lengths of of commercial battery electric city buses 12m ± 0.1m.

3.2.3 Passengers

The histograms of number of seats and max. passengers in 10-13m commercial electric city bus models, are presented in Figure 3.4. Based on this, the max. passengers of the concept bus is set to **85**, and the number of seats to **40**, which is intended to represent a typical bus. Data analysis showed a very weak correlation (0.15) between max. passengers and gross weight, hence the passenger count can be considered of second order importance compared to the gross weight in this work. Besides, it has no actual importance for the sizing of the electric machine, but could perhaps be of interest in the LCA use phase.



(a) Seats.



(b) Max. passengers.

Figure 3.4: Histogram for seats and max. passengers for 10-13m commercial electric city bus models.

3.2.4 Area, C_D, C_r and Wheel Radius

None of the bus manufacturers specify any of the parameters; equivalent frontal area, C_D, C_r and wheel radius. Instead, C_D and C_r are chosen based on what has been used in found references, whereas the area is estimated to be proportional to the bus width and height. The wheel radius is calculated using the tire dimensions, which are often specified.

The found data on area, C_D and C_r are presented in Table 3.2 [1].

Table 3.2: Area, WxH , C_D, C_r.

Length (m)	Curb Weight (kg)	A (m^2)	WxH	$\frac{A}{WxH}$	C_D	C_r	r (m)	Ref.
11.5	-	6.5	7.22	0.9	0.75	0.016	0.507	[110]
12.2	12 200	6.7	7.08	0.95	0.7	0.018	-	[111]
-	14 000	7.83	-	-	0.75	0.0076	0.512	[109]
-	9 375	7	-	-	0.7	0.0092	0.445	[112]
-	14 000	8	-	-	0.7	-	0.47	[113]
12.0	12 700	7.24	-	-	0.79	-	-	[114]

3.2.4.1 C_D

The six found values of aerodynamic drag coefficient, C_D, are between 0.7-0.79. The C_D for the concept BECB is set to **0.75**.

3.2.4.2 C_r

The four found values of rolling resistance coefficient, C_r, are between 0.0076-0.018. The C_r for the concept BECB is set to **0.013**, as a rounded average of the four.

3.2.4.3 Area

The cross sectional area can be estimated as the bus' height times it's width (HxW), however this is most probably an overestimation, since most vehicle fronts are more aerodynamically shaped than a rectangular. Therefore, this value can be multiplied with a factor less than one, to get an estimation of the effective cross sectional area. Since none of the bus manufacturers provide information of the effective cross sectional area, such a multiplication factor could not be established. Instead two academic references are used, (shown in Table 3.2), that provide both height and width as well as effective cross sectional area. One of the papers use a multiplication factor of 0.9 and the other one of 0.95. In Figure 3.5, these two factors are compared for the studied city buses, along with a linear curve fit for each factor. Since there is a large spread in data, the linear curve fit shows quite poor R^2 values. Using the suggested curves for a 12 m bus, result in an effective cross sectional area between $7.49 - 7.90\ m^2$, for the two multiplication factors. Here a worst case approach is adopted which result in an area of $\mathbf{7.90\ m^2}$ for the concept BECB.

[1] In reference [109], C_r is speed dependent as in $C_r = 0.0076 + 0.000056v$, where v is speed (m/s)

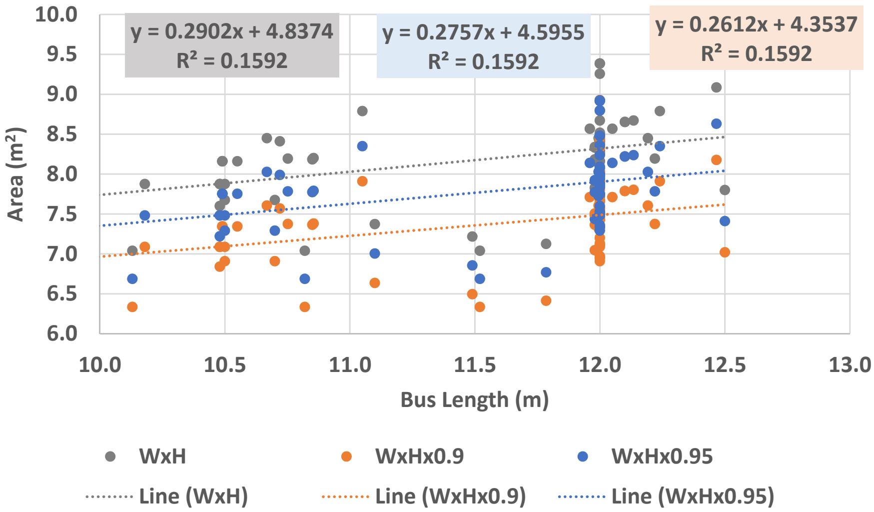


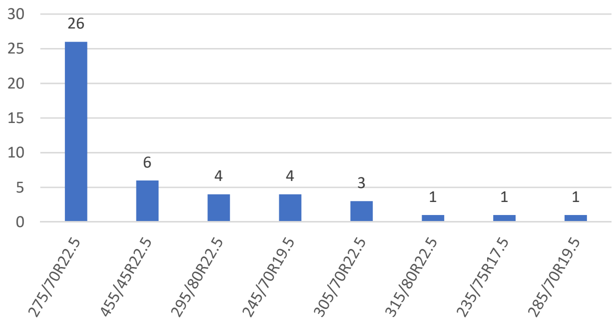
Figure 3.5: Comparison between three different cross sectional area estimations versus bus length of commercial battery electric city buses 10-13m, along with their linear fit. The area is estimated via the bus' frontal width (W) and height (H) via two different scaling factors of 0.9 and 0.95.

3.2.4.4 Tire Dimensions and Wheel Radius

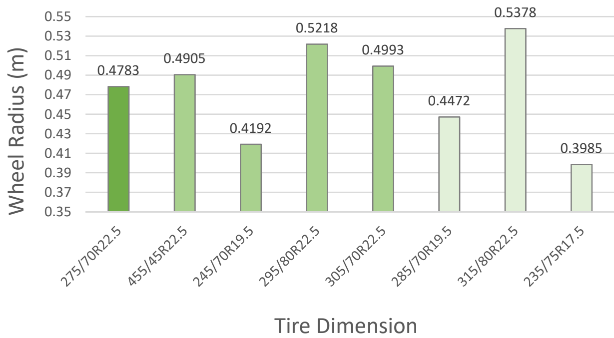
Tire dimensions are typically specified as *width* [mm] / *aspect ratio* [%] R *rim diameter* [inch]. The wheel radius,r_{wheel} can then be calculated as

$$r_{wheel} = 0.001\,\frac{25.4\,rim\,[inch] + \frac{2\,aspect\,ratio[\%]}{100}\,width[mm]}{2} \tag{3.2}$$

The number of commercial 10-13m battery electric city bus models for different tire dimensions is presented in Figure 3.6a. The most used tire dimension by far, is the 275/70R22.5, which is why it is also chosen for the concept BECB. The wheel radius of this dimension is estimated to **0.4783 m**, as presented in Figure 3.6b, along with the estimated wheel radius of the others tire dimensions.



(a) Number of bus models per tire dimension.



(b) Estimated wheel radius.

Figure 3.6: Used tire dimensions and their wheel radius, for tire dimensions used by commercial battery electric city buses 10-13m.

3.3 Bus Performance

3.3.1 Top Speed

A histogram of top speed for all found commercial battery electric city buses, i.e. including all models mentioned in Appendix C, shows that most buses have a top speed around 70-80 km/h, as shown in Figure 3.7. The average top speed of all city buses is 80.2 km/h. It is thus decided that the concept BECB should have a top speed of **80 km/h**, since it is a city bus.

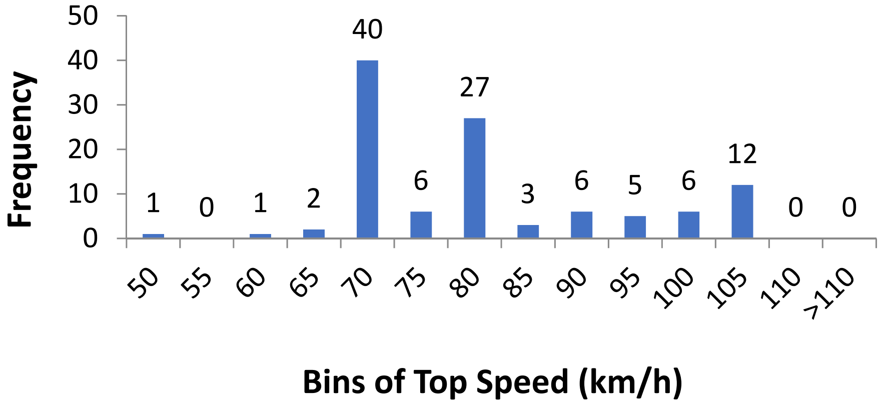


Figure 3.7: Histogram of top speed for all found commercial battery electric city buses.

3.3.2 Max. Road Grade

A histogram of max. road grade for 39 of all found commercial battery electric city buses, i.e. including all models mentioned in Appendix C, shows that most buses can manage road grades between 16%-20%, whereas some can manage as much as 24%-28%, as shown in Figure 3.8. The average max. road grade of all city buses is 20.2%. It is decided that the concept BECB is not to be one of the very high performing buses, hence the max. road grade of **20%** is targeted.

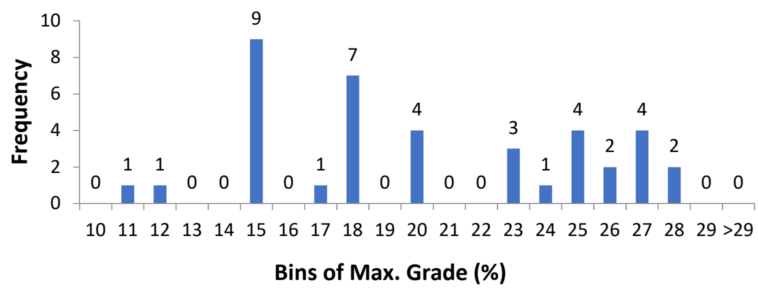


Figure 3.8: Histogram of max. road grade for all found commercial battery electric city buses.

The correlation between max. road grade level and bus top speed is shown in Figure 3.9. Some correlation exist but it is not very strong. For buses with a top speed of 80 km/h, a road grade of 18.8% can be expected.

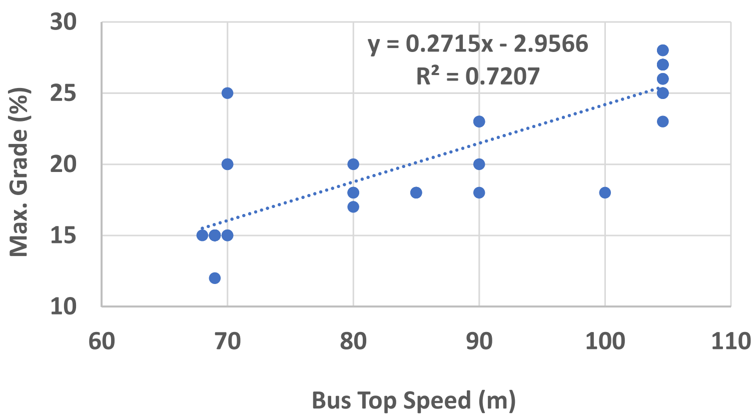


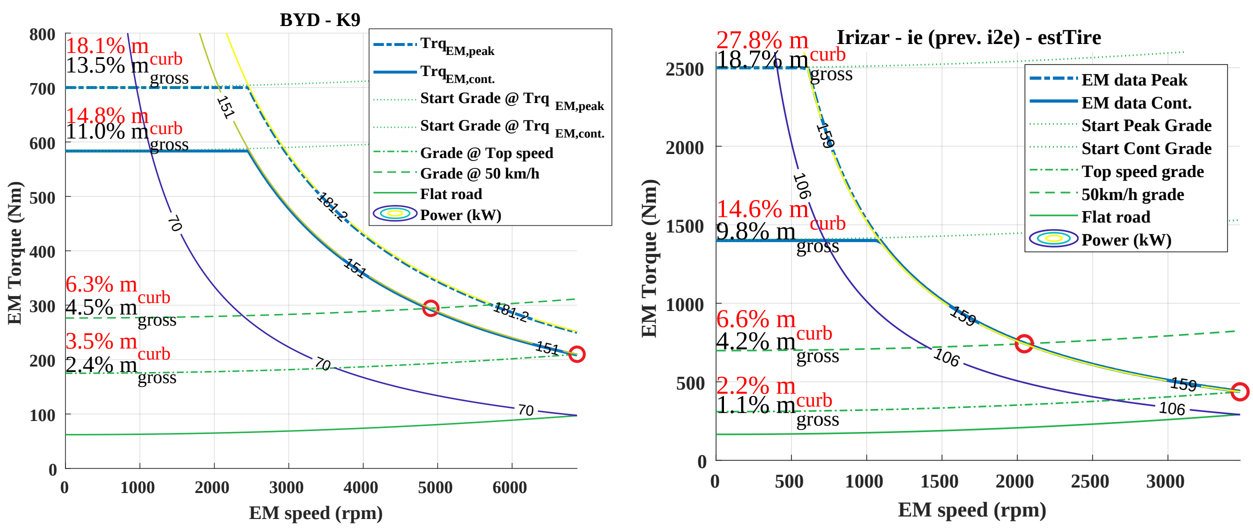
Figure 3.9: Max. road grade versus top speed for all found commercial battery electric city buses.

Furthermore, attempts have been made to do a back-calculation of the max. road grade on those bus models where enough other background data has been found, such as

- electric machine max. and rated/continuous torque and power
- tire dimensions
- gear ratio
- curb and gross bus weight
- bus width (W) and height (H), to estimate front area as 0.95xWxH
- bus top speed

Firstly, the peak and rated electric machine torque envelopes as functions of machine speed, are converted to wheel force as a function of vehicle speed, via the tire dimensions and the gear ratio; $Trq_{em}(n_{em}) \rightarrow F_{wheel}(v_{bus})$. Secondly, the available grading force as function of speed, is estimated by subtracting the vehicle road load (sum of aerodynamic drag and rolling resistance as functions of vehicle speed) from the max. and rated wheel force envelopes; $F_g = F_{wheel}(v_{bus} - F_{air+roll}$. Thirdly, the max. possible road grade is calculated as the arc-cos function of the ratio of the available grading force and the product of vehicle mass and gravity constant; $\Theta = \arccos\left(\frac{F_g}{mg}\right)$.

All this information was available for 9 models, whereas almost all were available for another 11 models for which either tire (275/70R22.5), gear ratio (TM4) or top speed (80km/h) was guessed. Furthermore, a C_d of 0.75 and a C_r of 0.013 are used. Only for two of the models were the specifications on max. grade available for comparison, see Figure 3.10, however for the Irizar model the curb weight is estimated to 12 000 kg. Based on the results, it is difficult to determine whether the max. grade is specified for continuous or peak torque and for curb or gross weight.



(a) BYD K9, specified max. grade: 15% grade, top speed: 70 km/h.

(b) Irizar ie, specified max. grade: 18%, top speed: 85 km/h.

Figure 3.10: Estimated max. grade for two commercial battery electric city buses 10-13m.

As a comparison, estimated max. road grade for all 20 bus models are shown in Figure 3.11, based on continuous torque for gross weight, along with some comparative values where also curb weight is available. In Figure 3.11, estimated max. road grade for the same bus models are shown, but based on peak torque instead. In both figures, found data of specified max. road grade for two bus models are included. For the BYD model, the specified data match the estimated max. grade using the continuous torque and gross buss weight. For the other model, by Irizar, the specified data instead match closely to the estimated max. grade using the peak torque and the gross weight. Based on this result it is still difficult to conclude generally applicable references for specified values of max. road grade; i.e. whether it applies to peak or continuous torque and curb or gross bus weight.

The colors in Figure 3.11 and Figure 3.11, represent different electric machine models. From left, red stands for BYD's TYC-90A, bright green is Siemens 1DB2016, light green Siemens 1DB2016 new, dark green Siemens 1DB2022, orange TM4, blue ZF Ave130 and yellow Ziehl-Abegg's machine. Interestingly, bus models with the same electric machine model often shows similar max. grade estimations. Still, since it is unclear under which conditions max. grade is normally specified, these estimated grades can only be used as a vague reference.

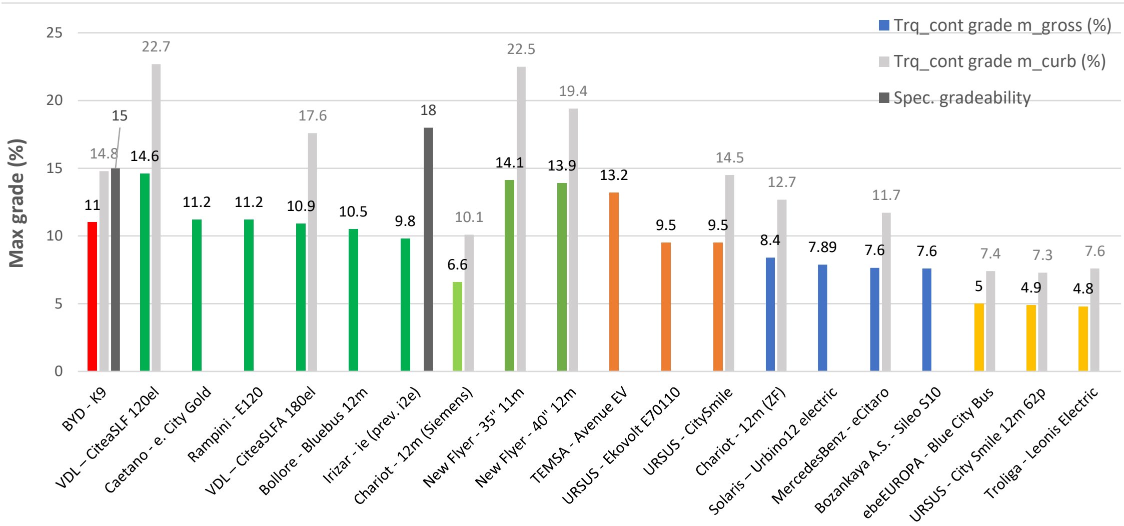


Figure 3.11: Estimated max. grade, considering **continuous torque** and bus **gross weight**, as well as **curb weight** if available, along with two found values for max. grade in dark gray.

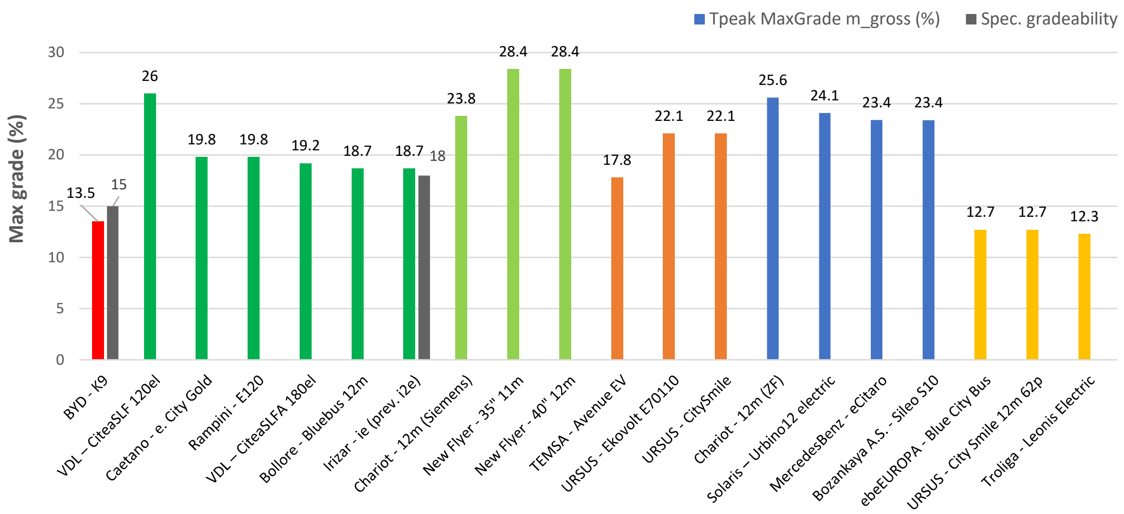


Figure 3.12: Estimated max. grade, considering **peak torque** and bus **gross weight**, along with two found values for max. grade in dark gray.

3.3.3 Acceleration

Very little data has been found regarding acceleration times on the different bus models. Only five models state acceleration times; 4.5s (0-32km/h), 6s (0-30km/h) and 7.8s (0-32km/h), 18s (0-50km/h) and 23s (0-50km/h).

According to a senior research engineer at a local bus manufacturer likewise project partner, the maximum acceleration is often limited to around 1.5-2 m/s^2, for passenger comfort [115].

Furthermore, according to the found official city drive cycles for buses (summarized in Table 4.1), acceleration levels reach up to 2.91 m/s^2 in the New York cycle, whereas, the highest acceleration level among the European drive cycles is 2.13 m/s^2, in the Braunschweigh cycle.

For the same 20 buses as for the grade estimation, here the max. acceleration is estimated based on **electric motor total peak torque**, and bus road load, shown in Figure 3.13. The average estimated max. acceleration using gross weight is 1.7 m/s^2, and for curb weight it is 2.5 m/s^2.

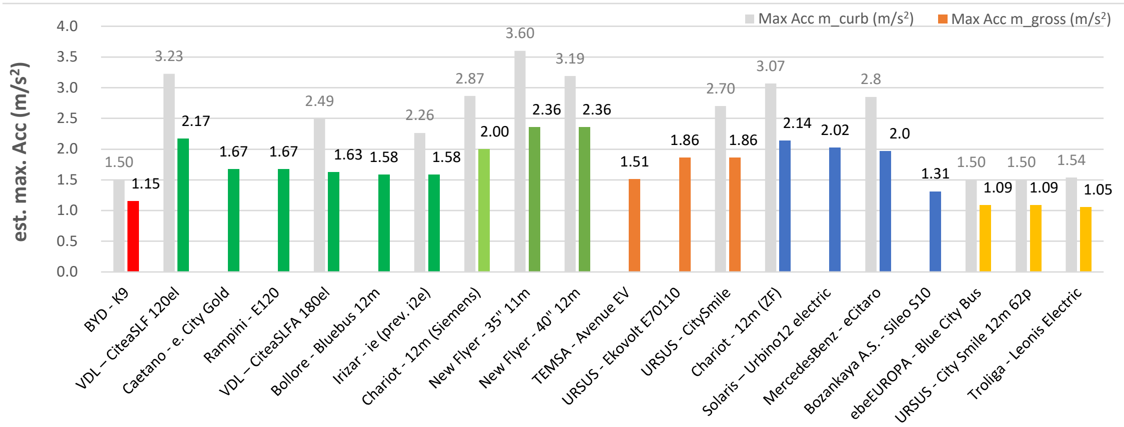


Figure 3.13: Estimated max. acceleration, considering bus gross weight, as well as curb weight if available, including a mass factor of 1.1 (m_{acc}=1.1 $m_{gross/curb}$).

The max. acceleration level for the concept BECB is set to **1.5 m/s^2 with gross bus weight**. Due to lack of data, a specific requirement for a certain acceleration time is however not specified.

A road grade of 20% demands the same force as an acceleration of 1.92 m/s^2, when assuming the same vehicle mass for both grade and acceleration. Hence the 20% road grade will not be realized at full load.

3.4 Gear and Electric Machine Requirements

Rather than to resemble a specific electric motor model, the electric motor for the concept BECB is aimed to represent a typical electric machine for a BECB.

3.4.1 Electric Machine Max. Speed and Gear Ratio

A histogram of max. EM speed for the 10-13m commercial BECB models is presented in Figure 3.14.

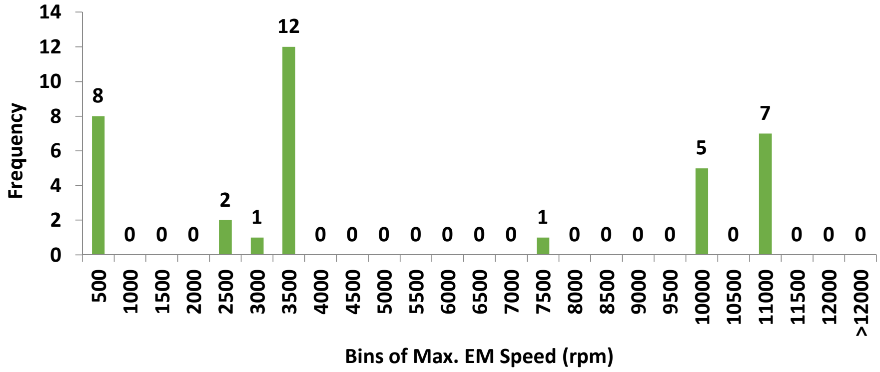


Figure 3.14: Histogram of max EM speed for 10-13m commercial battery electric city buses.

The found data indicate that three main groups of machine max. speed ratings are used (ignoring the one machine at 7500 rpm); high, middle and low. Even if data for the shorter and longer city buses are included, the result is relatively similar, only the frequency values increases somewhat (11 at 500 rpm, 4 at 2500 rpm, 20 at 3500 rpm, 1 at 4500 rpm, 6 at 10 000 rpm and 11 at 11 000 rpm).

The very low speed machines are wheel hub motors with neither transmission nor differential. This solution saves both the mass of the transmission and its losses, hence a lower energy consumption is anticipated.

For this project, based on found data, three alternative machines **could be** derived, as described in Table 3.3. Then the gear ratio has been estimated as the ratio of the max. machine speed ($w_{wheel,max}$) over the wheel speed ($w_{em,max}$) at bus's top speed as in

$$k_{gear} = \frac{w_{em,max}}{w_{wheel,max}} = \frac{n_{em,max}\frac{\pi}{30}}{\frac{v_{car,max}}{3.6\, r_{wheel}}} \tag{3.3}$$

Table 3.3: Alternative electric machine max. speed and gear ratios.

Alternatives	Speed	gear/transmission	gear ratio
A. high speed	11 000 rpm	transmission (differential if 1 EM)	24.79
B. middle speed	3 500 rpm	transmission (differential if 1 EM)	7.89
C. low speed	500 rpm	wheel motor (no transmission/differential)	1.00

Since all three speed levels, according to this study, are found to be almost equally common in commercial BECBs, either speed level could be used. Nevertheless, it is decided that the high speed level shall be used for the concept BECB, based on the following:

- It is anticipated that electric bus manufacturers are willing to adopt an already available electric machine design in order to limit their development costs.
- Light duty vehicle sales volumes are much higher than those for buses. In electrified versions of these applications, often high speed machines are used. Hence, they are likely very interesting also for BECBs, however possibly with minor adjustments, such as end winding potting or cooling system adjustments.
- It is also assumed that bus manufacturers are interested in a dual electric motor system which can fit in a single drive axis much like the Ave130 from ZF, in favour of a low floor and a larger passenger compartment

3.4.2 Electric Machine Torque and Power Rating

The total peak torque rating for the two electric motors in the concept BECB is directly calculated from the max. acceleration level of 1.5 m/s^2 with gross weight, and becomes **655 Nm** (327.5 Nm per motor), as in

$$T_{em,max} = \frac{F_{acc} + F_{air(30km/h)} + F_{roll}}{k_{gear}\,\eta_{gear}} = \frac{a_{max}\,(m_{gross}\,m_{mf}) + 0.5\rho_{air}C_d A(\frac{30}{3.6})^2 + C_r m_{gross}\, g}{k_{gear}\,\eta_{gear}} \tag{3.4}$$

where m_{mf} is the mass factor representing additional rotational masses, set to 1.1, ρ_{air} is the air density set to 1.2 kg/m^3, g the earth's gravitational constant set to 9.81 m/s^2 and η_{gear} the gear efficiency set to 97%.

Histograms of the total peak power for 10-13m commercial BECBs, are shown in Figure 3.15, indicating a very wide spread, however most machines are between 160-300 kW. The average total peak power is 253 kW for the whole range, and 217 kW for the range 160-300 kW. It is decided that the concept BECB should have a total peak power of **250 kW** (125 kW per motor).

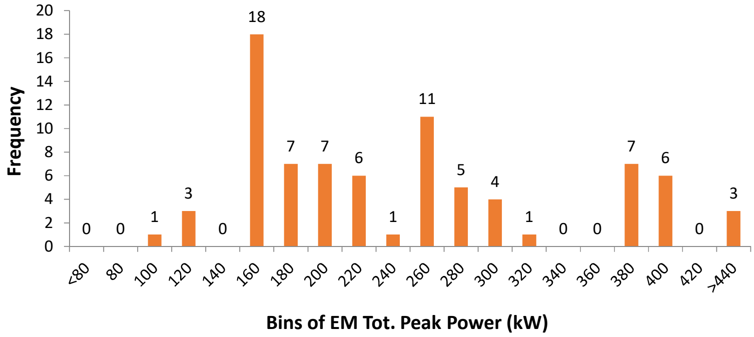
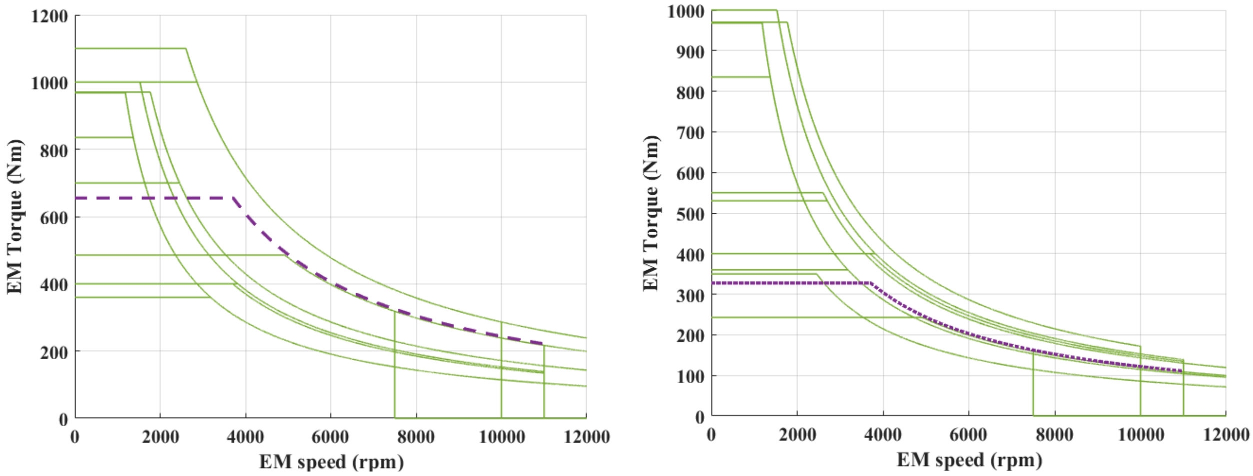


Figure 3.15: Electric motor total peak power for 10-13m commercial battery electric city buses.

The estimated electric machine peak torque-power curve as a function of speed for commercial battery electric city buses 10-13m, using high speed machines, is presented in Figure 3.16, along with the suggested pair of machines for the concept BECB.

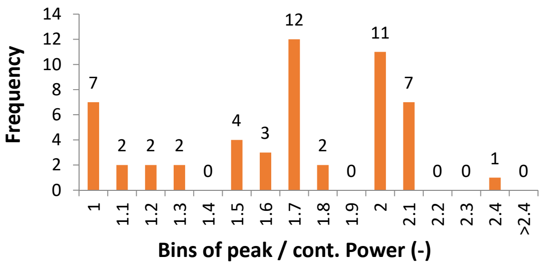


(a) Total. **(b)** Per electric machine.

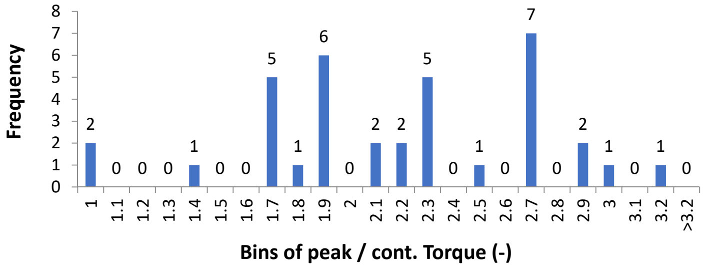
Figure 3.16: Estimated electric machine peak torque-power curve as a function of speed for commercial battery electric city buses 10-13m.

The ratio of peak over rated/continuous for both power and torque is shown in Figure 3.17. The average value for power is 1.6 and it is 2.1 for torque. It is chosen that for the concept BECB, the ratio for power is **1.7**, and **2.3** for torque. That is, a total rated/continuous power of **147 kW** and a total rated/continuous torque of **284 Nm**.

In order to evaluate if these figures will actually be reached by the electric machine, not only electromagnetic simulations are necessary, but also thermal and fluid dynamics simulation are needed. It will not be possible to spend the necessary time to manage these calculations within this project. Hence, any time limit for the peak torque will not be defined. Instead it is simply assumed that it can be realized as demanded by the drive cycles.



(a) Power.



(b) Torque.

Figure 3.17: Ratio of electric machine peak and rated/continuous power and torque, used in commercial battery electric city buses 10-13m.

3.4.3 Electric Machine Voltage and Current Rating

The data show that the most widely used range of dc voltage level in 10-13m commercial battery electric city buses is 580-600 V, as shown in Figure 3.18. Still, some buses use 400V. It is therefore decided that the power rating of the electric machine will be calculated using a dc-voltage of **580 V**.

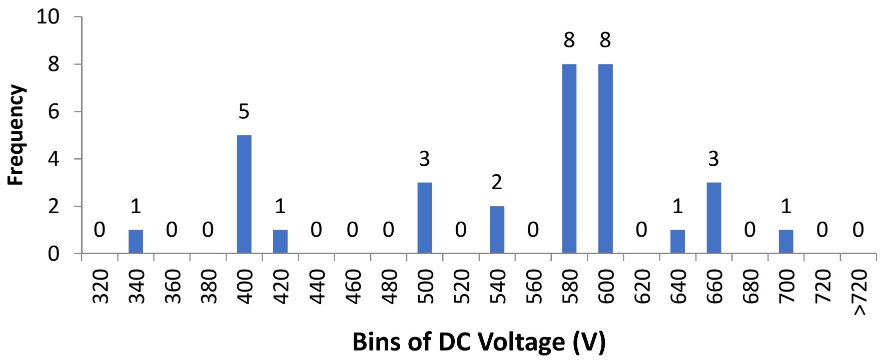


Figure 3.18: Histogram of nominal dc voltage for 10-13m commercial battery electric city buses.

Current rating is very seldom stated by the bus manufacturers. Another way to acquire such information is from the electric motor and controller manufacturers, as seen in Table 2.7. It is decided that the max. rms phase currrent of the concpet BECB electric motor should be **280 A**.

3.4.4 Electric Machine Dimensional Limits

No data has been found on vital dimensions of the used commercial electric machines, such as stack length and stator outer diameter. Instead, for the concept BECB electric motor, these limitations are roughly estimated based on the technical drawing of the ZF Ave130 drive axle in [87]. Then the stator outer diameter is estimated to 270 mm and the stack length to 174 mm. It means that the electric motor of the concept BECB should not have a stack length longer than roughly **200 mm**, nor a stator outer diameter wider than approximately **280 mm**.

3.5 Specifications for the Project's Battery Electric City Bus

The selected battery electric bus specifications which will be used in the project is summarized in Table 3.4.

Table 3.4: Specifications for the battery electric bus to be used in this project.

Parameter	Value	Unit
Length	12.0	m
Curb Weight, m_{curb}	13 000	kg
Gross Weight, m_{gross}	18 400	kg
Rotating mass coefficient, δ	1.1	-
Max. Passengers	85	-
Seats	40	-
Frontal Area, A	7.9	m^2
Aerodynamic drag coefficient, $\mathrm{C_D}$	0.75	-
Wheel radius	0.4783	m
Rolling resistance coefficient, Cr	0.013	-
Top Speed	80	km/h
Max. Grade ($\mathrm{m_{cur}}$)	$\geq$20	%
Max. Acc. ($\mathrm{m_{gross}}$)	1.5	$\mathrm{m/s^2}$
$\mathrm{F_{wheel,max}}$	35.0	kN
$\mathrm{n_{wheel,max}}$	443.7	rpm
Gear ratio	24.7907	-
EM max. speed	11 000	rpm
Number of electric machines	2	
Tot. Peak EM Power (2xEMs)	250 (2x125)	kW
Tot. Peak EM Torque (2xEMs)	655 (2x327.5)	Nm
Max. dc-bus voltage	580	V
Max. rms phase current	280	A
Max. stator outer diameter	280	mm
Max. stack length	200	mm

A rough evaluation of the expected bus performance with the selected specifications for the electric machine, is presented in Figure 3.19. The max. achievable road grade and peak acceleration is calculated at low speed with ideal peak and continuous torque, as well as for the continuous torque envelope at 50 km/h and the top speed 80 km/h. All calculations are done with either the curb or the gross bus weight, and rotating masses are accounted for during acceleration.

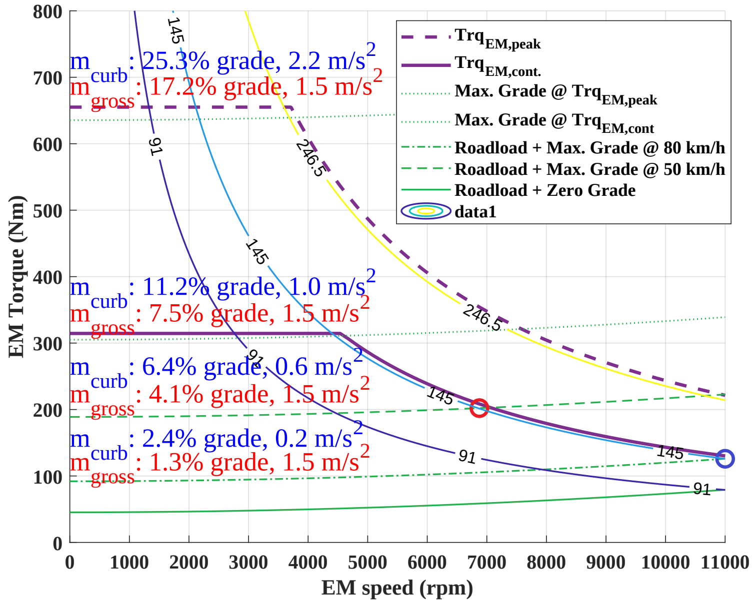
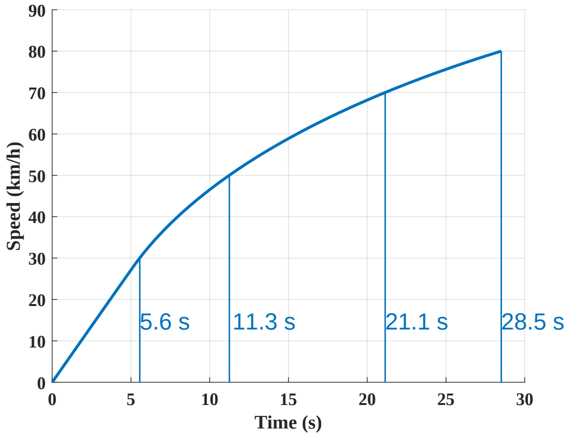


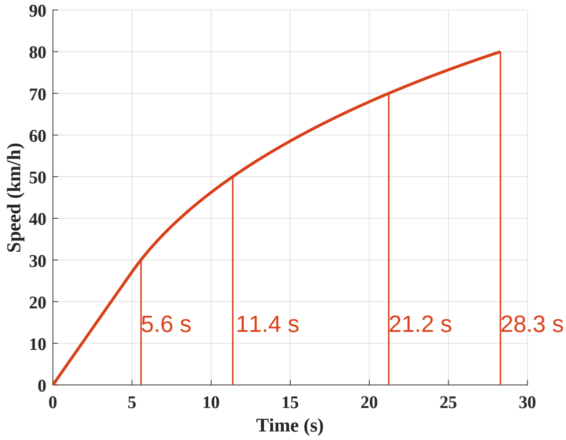
Figure 3.19: Estimated max. grade levels at peak and continuous starting torque, at 50 km/h and at 80 km/h.

Estimated acceleration time with curb and gross weight, both including a rotating mass factor of 1.1, to also consider the rotating masses.

Starting from the ideal peak torque as function of time, combined with the road load on a flat road, the shortest time to accelerate from stand still to top speed, is calculated and shown in Figure 3.20, both with curb and gross bus weight.



(a) Curb weight.



(b) Gross weight.

Figure 3.20: Estimated acceleration time (0-X km/h) for the reference battery electric city bus.

3.6 Reference Electric Machine

The reference electric machine is a Permanent Magnet Synchronous Machine (PMSM) with a distributed copper winding with 4 parallel branches, and v-shaped interior Nd(Dy)FeB magnets, as shown in Figure 3.21. The design is based on the 100 kW machine used for the light duty vehicle in this project [116], with the minor changes:

- The stator outer diameter is increased to **210 mm** from 200 mm
- The stack length is increased to **138 mm** from 127mm
- The number of turns are increased to **9**, from 7
- The current and voltage ratings are increased to **280 Arms** from 260 Arms, and to **580 Vdc** from 430 Vdc
- The width and height of the slot are slightly increased about 21% and 9% respectively, to reduce the copper losses, since the current rating is slightly increased
- The max. speed is reduced to **11 000 rpm** instead of 12 000 rpm
- The base speed is slightly reduced to around **3600 rpm** instead of 4000 rpm

The machine was modeled in the finite element analysis (FEA) software ANSYS Maxwell 2D. The resulting electromagnetic efficiency with sinusoidal current excitation and maximum torque per ampere current control (with respect to both the current and voltage limitations) is shown in Figure 3.22.

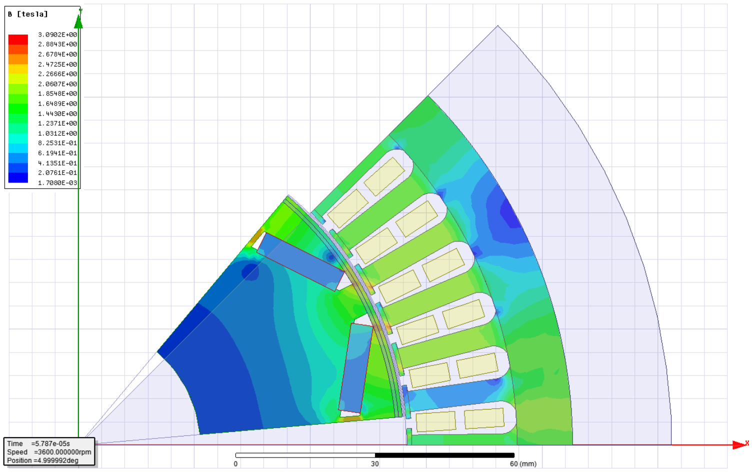


Figure 3.21: Reference PMSM lamination cross section as modeled in 2D in the FEA software ANSYS Maxwell, along with the magnitude of the magnetic field density, B, at peak torque and base speed.

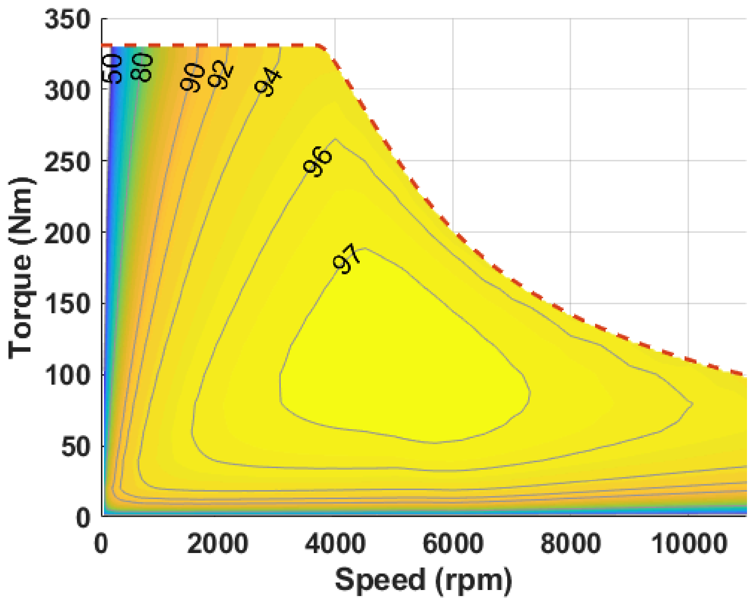


Figure 3.22: Reference PMSM electromagnetic efficiency (%).

Chapter 4

Bus Drive Cycles - Official

Historically, for heavy duty vehicles, engine-dynamometer test cycles have been used for emission legislation rather than chassis-dynamometer cycles (which is used for light duty vehicles). The reason is the large variety in both construction and driving conditions between different heavy vehicles, which makes a chassis-dynamometer test procedure complex and rather expensive [117]. Still, there are a number of developed drive cycles for heavy duty vehicles, some of which specifically represent bus driving. In this chapter, all of the found bus drive cycles are presented. For further reading on drive cycles, see [117] and to some extent [118].

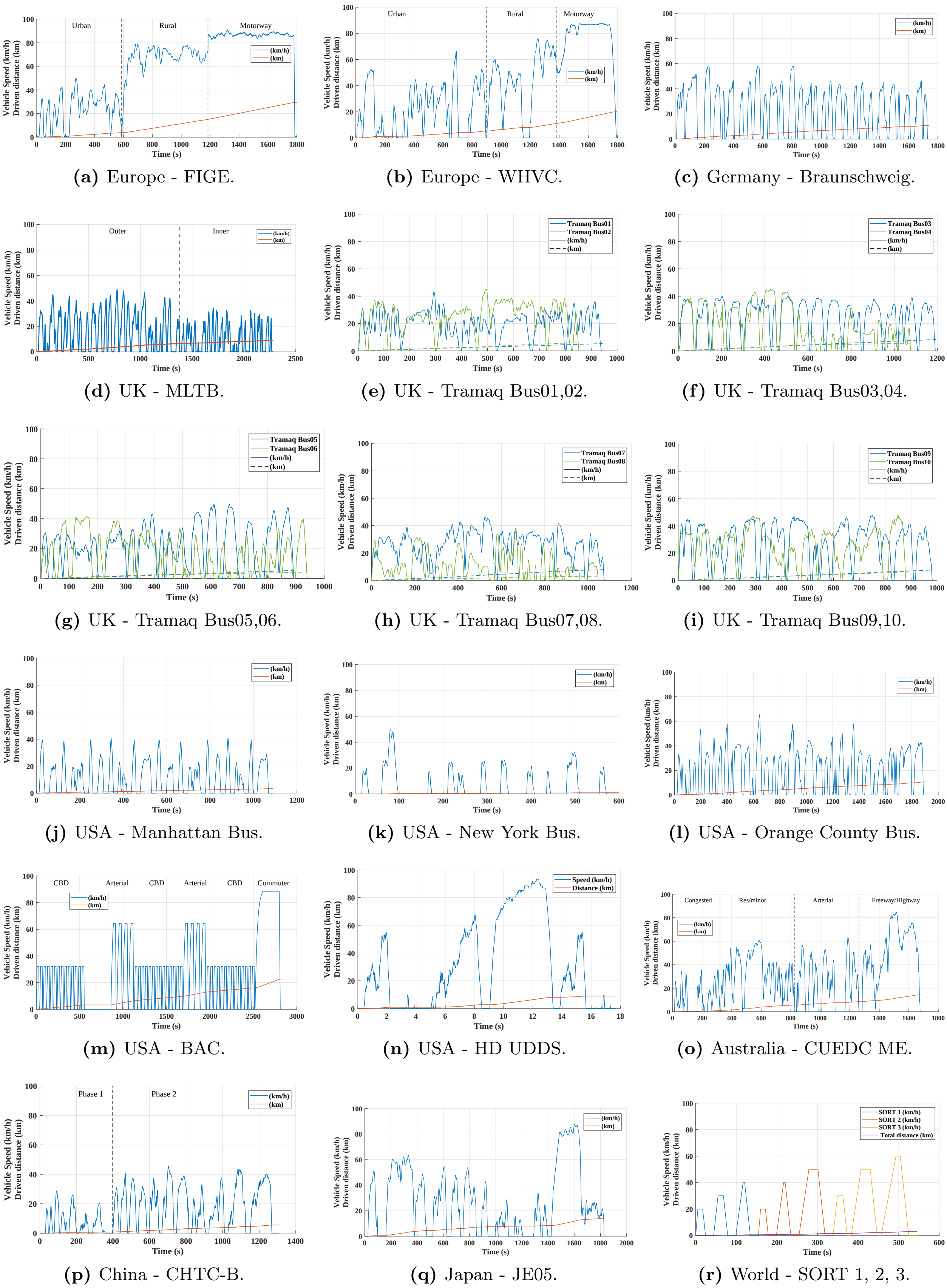
4.1 Bus Cycle Data and Speed Profiles

Calculated characteristic data on the found official bus drive cycles are shown in Table 4.1.

Table 4.1: Official bus drive cycles data summary.

Cycle	Cycle duration (s)	Driven distance (m)	Max. speed (km/h)	Average speed (km/h)	Average running speed (km/h)	Std. speed (km/h)	Time share standing (%)	Time share <60 km/h (%)	Time share 60-90 km/h (%)	Time share > 90 km/h (%)	Max. pos. acc. (m/s^2)	Max. neg. acc (m/s^2)	Average pos. acc. (m/s^2)	Average neg. acc. (m/s^2)	Std. pos. acc. (m/s^2)	Std. neg. acc. (m/s^2)	Time share a<1 m/s2 (%)	Time share 1<a<2 m/s2 (%)	Time share 2<a<3 m/s2 (%)	Time share a>3 m/s2 (%)	Time share pos. acc. (%)	Time share neg. acc. (%)	No Acc.	No. Dec.	No Acc./dist (#/km)	No. Dec./dist (#/km)	RPA (m/s^2)
Braunschweig	1 740	10 873	58.2	22.5	30.1	18.3	28.7	71.3	0.0	0.0	2.13	-3.11	0.50	-0.66	0.44	0.61	94.3	5.5	0.3	0.0	43	32	77	70	7.1	6.4	0.21
FIGE	1 800	29 492	91.1	59.0	59.0	28.7	5.6	31.5	62.4	0.5	1.99	-4.03	0.18	-0.20	0.20	0.39	99.9	0.1	0.0	0.0	49	43	154	156	5.2	5.3	0.06
FIGE Urban	586	3 824	49.9	23.5	23.5	13.3	14.2	85.8	0.0	0.0	0.86	-1.36	0.27	-0.33	0.21	0.31	100.0	0.0	0.0	0.0	50	41	25	25	6.5	6.5	0.13
FIGE Rural	599	11 235	78.6	67.5	67.5	11.7	0.3	10.0	89.6	0.0	1.99	-1.08	0.18	-0.13	0.19	0.14	99.8	0.2	0.0	0.0	52	44	32	32	2.8	2.8	0.08
FIGE Motorway	614	14 410	91.1	84.4	84.4	14.1	2.4	0.7	95.4	1.5	1.96	-4.03	0.06	-0.14	0.12	0.55	100.0	0.0	0.0	0.0	45	45	97	99	6.7	6.9	0.03
MLTB	2 281	8 968	48.7	14.1	20.5	13.4	33.5	66.5	0.0	0.0	1.13	-2.15	0.46	-0.63	0.24	0.45	99.5	0.5	0.0	0.0	42	31	98	102	10.9	11.4	0.23
MLTB Inner	901	2 502	34.4	10.0	15.9	10.3	40.7	59.2	0.0	0.0	1.12	-2.15	0.48	-0.65	0.26	0.47	99.2	0.7	0.0	0.0	39	29	48	49	19.2	19.6	0.26
MLTB Outer	1 380	6 465	48.7	16.9	23.2	14.5	28.6	71.4	0.0	0.0	1.13	-1.98	0.44	-0.62	0.23	0.44	99.6	0.4	0.0	0.0	44	32	50	53	7.7	8.2	0.22
WHVC	1 800	20 072	87.8	40.1	46.5	29.5	15.9	57.3	26.8	0.0	1.51	-1.67	0.27	-0.31	0.25	0.35	99.3	0.7	0.0	0.0	46	40	114	114	5.7	5.7	0.10
WHVC Urban	900	5 321	66.2	21.3	27.3	18.1	25.9	72.9	1.2	0.0	1.51	-1.67	0.34	-0.44	0.27	0.41	98.8	1.2	0.0	0.0	45	35	32	31	6.0	5.8	0.17
WHVC Rural	481	5 818	75.9	43.5	47.8	22.4	9.6	64.7	25.8	0.0	1.04	-1.45	0.30	-0.26	0.22	0.25	99.8	0.2	0.0	0.0	48	43	19	19	3.3	3.3	0.13
WHVC Motorway	419	8 933	87.8	76.6	77.6	18.8	1.7	15.3	83.1	0.0	0.39	-1.15	0.09	-0.16	0.10	0.24	100.0	0.0	0.0	0.0	45	48	63	64	7.1	7.2	0.04
SORT 1	155	520	40.0	12.1	19.8	12.8	41.6	58.4	0.0	0.0	1.03	-0.80	0.73	-0.80	0.15	0.00	96.5	3.5	0.0	0.0	22	20	3	3	5.8	5.8	0.21
SORT 2	184	920	50.0	18.0	26.7	18.1	35.1	64.9	0.0	0.0	1.03	-0.80	0.64	-0.80	0.14	0.00	97.1	2.9	0.0	0.0	26	21	3	3	3.3	3.3	0.19
SORT 3	206	1 450	60.0	25.3	31.4	20.1	21.8	78.2	0.0	0.0	0.77	-0.80	0.54	-0.80	0.11	0.00	100.0	0.0	0.0	0.0	35	24	3	3	2.1	2.1	0.19
Bus01 TCrhump	944	5 315	43.3	20.2	20.9	8.7	5.7	94.3	0.0	0.0	1.25	-1.53	0.33	-0.39	0.26	0.34	99.2	0.8	0.0	0.0	52	45	57	57	10.7	10.7	0.17
Bus02 TCother	855	5 938	45.3	25.0	26.0	10.6	6.1	93.9	0.0	0.0	1.41	-1.81	0.26	-0.30	0.26	0.29	98.7	1.3	0.0	0.0	51	46	52	52	8.8	8.8	0.12
Bus03 BusLane	1 192	8 343	39.9	25.2	27.3	12.6	11.2	88.8	0.0	0.0	1.52	-1.44	0.31	-0.34	0.33	0.36	96.7	3.3	0.0	0.0	49	45	49	49	5.9	5.9	0.12
Bus04 CycLane	1 080	5 652	45.0	18.8	20.9	13.8	14.2	85.8	0.0	0.0	1.42	-2.30	0.29	-0.27	0.32	0.32	98.0	2.0	0.0	0.0	45	48	46	44	8.1	7.8	0.12
Bus05 TLights	894	5 412	49.6	21.8	24.5	14.3	15.2	84.8	0.0	0.0	1.68	-1.58	0.43	-0.44	0.34	0.39	96.0	4.0	0.0	0.0	45	44	37	35	6.8	6.5	0.18
Bus06 OneWay	941	4 356	41.4	16.6	19.2	12.6	20.0	80.0	0.0	0.0	1.51	-1.47	0.43	-0.42	0.32	0.35	96.9	3.1	0.0	0.0	43	44	47	49	10.8	11.2	0.18
Bus07 MiniRnd	1 076	7 878	46.5	26.3	26.7	10.0	2.6	97.4	0.0	0.0	1.24	-1.50	0.27	-0.26	0.26	0.26	98.7	1.3	0.0	0.0	48	51	57	57	7.2	7.2	0.11
Bus08 ctrlCon	1 051	3 078	38.2	10.5	12.0	8.9	19.7	80.3	0.0	0.0	1.13	-1.47	0.28	-0.27	0.26	0.28	99.6	0.4	0.0	0.0	44	45	46	49	14.9	15.9	0.14
Bus09 ctrlNonCon	983	7 607	47.7	27.8	29.8	14.6	10.1	89.9	0.0	0.0	1.54	-1.96	0.40	-0.43	0.36	0.42	95.2	4.8	0.0	0.0	49	44	50	52	6.6	6.8	0.15
Bus10 ctrlSub	886	6 394	48.0	26.0	27.3	12.5	7.6	92.4	0.0	0.0	1.41	-1.22	0.30	-0.31	0.29	0.29	98.4	1.6	0.0	0.0	48	47	59	58	9.2	9.1	0.12
Manhattan Bus	1 089	3 325	40.9	11.0	17.2	11.8	40.3	59.7	0.0	0.0	2.24	-2.68	0.62	-0.79	0.39	0.50	95.3	4.3	0.5	0.0	31	24	242	176	72.8	52.9	0.28
New York BUS	600	989	49.6	5.9	17.2	10.4	67.6	32.4	0.0	0.0	2.91	-2.24	1.25	-0.73	0.78	0.54	93.9	2.1	4.0	0.0	12	20	47	78	47.5	78.8	0.38
Orange County Bus	1 909	10 526	65.4	19.8	25.2	16.6	27.6	71.9	0.5	0.0	1.73	-2.27	0.44	-0.60	0.39	0.55	93.8	6.2	0.0	0.0	47	35	65	65	6.2	6.2	0.21
HD UDDS	1 060	8 935	93.3	30.3	45.4	31.9	35.3	42.4	18.9	3.5	1.69	-1.81	0.37	-0.47	0.31	0.37	98.6	1.4	0.0	0.0	32	25	80	69	9.0	7.7	0.12
TCODC BAC	2 830	22 621	88.5	28.8	37.9	26.0	24.0	59.2	16.8	0.0	0.96	-2.06	0.68	-1.57	0.27	0.58	100.0	0.0	0.0	0.0	28	12	51	51	2.3	2.3	0.14
TCODC BAC CBD	560	3 292	32.2	21.1	25.7	13.1	17.5	82.5	0.0	0.0	0.89	-2.01	0.82	-1.49	0.17	0.62	100.0	0.0	0.0	0.0	27	15	14	14	4.3	4.3	0.17
TCODC BAC Arterial	270	3 155	64.4	41.9	47.7	24.1	11.9	47.4	40.7	0.0	0.89	-1.99	0.58	-1.79	0.23	0.41	100.0	0.0	0.0	0.0	46	15	4	4	1.3	1.3	0.20
TCODC BAC Commuter	310	6 434	88.5	74.5	80.1	27.0	6.8	11.0	82.3	0.0	0.96	-2.06	0.27	-1.89	0.26	0.38	100.0	0.0	0.0	0.0	29	4	1	1	0.2	0.2	0.05
CUEDC ME	1 679	14 388	85.0	30.8	36.3	22.7	15.6	73.6	10.8	0.0	2.78	-2.40	0.49	-0.56	0.41	0.51	94.8	4.9	0.3	0.0	46	40	89	89	6.2	6.2	0.21
CUEDC ME Arterial	438	2 862	63.3	23.5	32.9	19.6	29.0	68.9	2.1	0.0	2.37	-2.32	0.69	-0.68	0.44	0.53	91.6	8.0	0.5	0.0	36	37	16	16	5.6	5.6	0.29
CUEDC ME Congested	324	996	36.4	11.0	16.4	10.9	34.0	66.0	0.0	0.0	2.69	-2.22	0.57	-0.60	0.42	0.42	95.1	4.6	0.3	0.0	36	34	18	18	18.1	18.1	0.29
CUEDC ME FreewayHighway	417	5 845	85.0	50.3	53.7	23.3	6.0	54.4	39.6	0.0	2.78	-1.63	0.34	-0.38	0.40	0.38	97.4	2.2	0.5	0.0	50	45	27	27	4.6	4.6	0.14
CUEDC ME ResMinor	509	4 684	60.7	33.1	33.7	16.1	1.8	96.9	1.4	0.0	1.64	-2.40	0.46	-0.61	0.34	0.58	95.5	4.5	0.0	0.0	57	42	28	28	6.0	6.0	0.22
CHTC-B	1 310	5 489	45.6	15.1	19.8	13.6	28.2	71.8	0.0	0.0	1.26	-1.32	0.37	-0.40	0.28	0.35	99.1	0.9	0.0	0.0	41	37	91	86	16.6	15.7	0.17
JE05	1 829	13 892	87.6	27.3	36.5	25.7	26.2	62.5	11.3	0.0	1.48	-1.72	0.31	-0.32	0.27	0.33	98.7	1.3	0.0	0.0	39	38	71	72	5.1	5.2	0.12

The speed profiles of the drive cycles are presented in Figure 4.1.



(a) Europe - FIGE. **(b)** Europe - WHVC. **(c)** Germany - Braunschweig.

(d) UK - MLTB. **(e)** UK - Tramaq Bus01,02. **(f)** UK - Tramaq Bus03,04.

(g) UK - Tramaq Bus05,06. **(h)** UK - Tramaq Bus07,08. **(i)** UK - Tramaq Bus09,10.

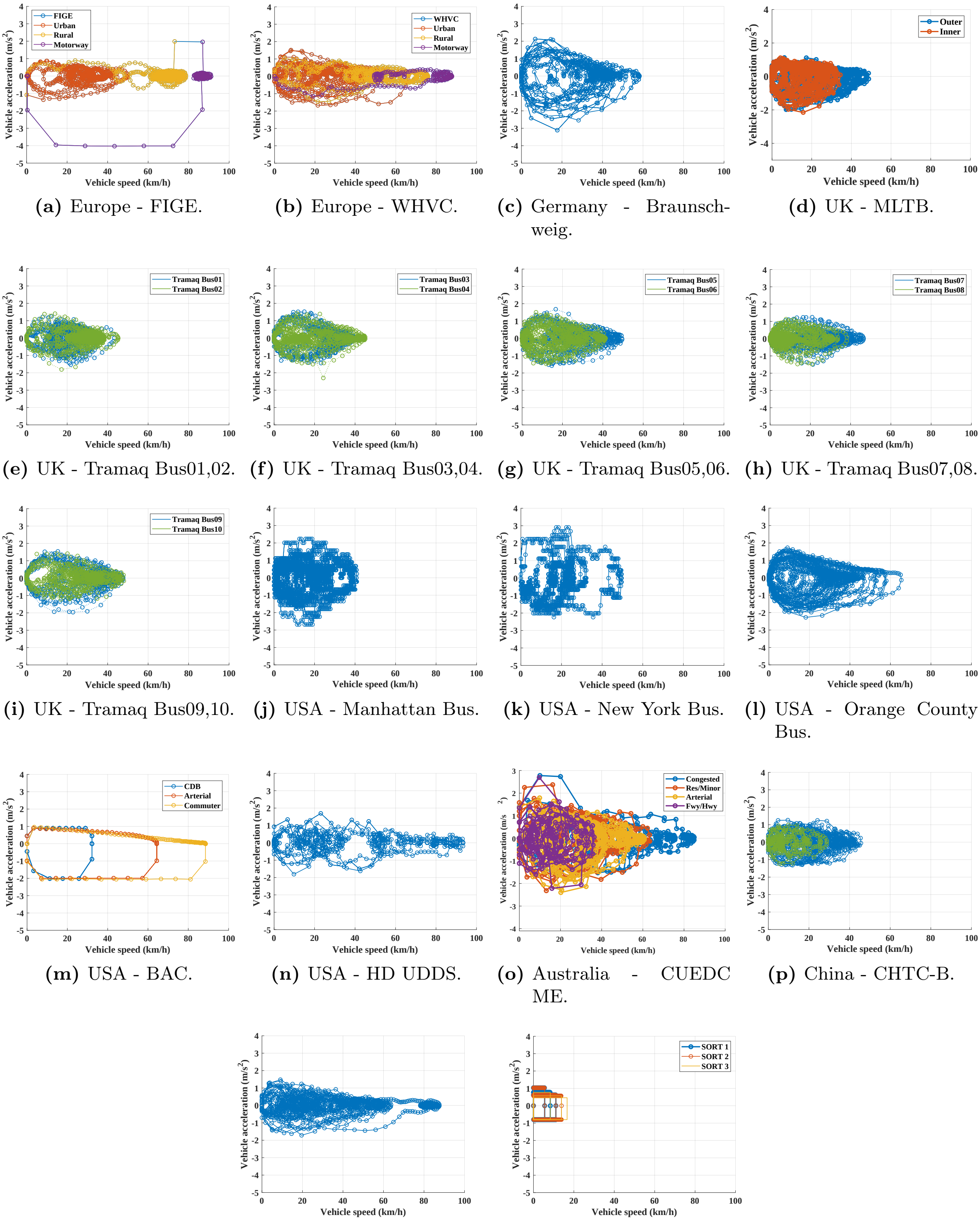
(j) USA - Manhattan Bus. **(k)** USA - New York Bus. **(l)** USA - Orange County Bus.

(m) USA - BAC. **(n)** USA - HD UDDS. **(o)** Australia - CUEDC ME.

(p) China - CHTC-B. **(q)** Japan - JE05. **(r)** World - SORT 1, 2, 3.

Figure 4.1: Drive cycle speed profiles.

The acceleration-speed operating points are shown in Figure 4.2.



(a) Europe - FIGE. **(b)** Europe - WHVC. **(c)** Germany - Braunschweig. **(d)** UK - MLTB. **(e)** UK - Tramaq Bus01,02. **(f)** UK - Tramaq Bus03,04. **(g)** UK - Tramaq Bus05,06. **(h)** UK - Tramaq Bus07,08. **(i)** UK - Tramaq Bus09,10. **(j)** USA - Manhattan Bus. **(k)** USA - New York Bus. **(l)** USA - Orange County Bus. **(m)** USA - BAC. **(n)** USA - HD UDDS. **(o)** Australia - CUEDC ME. **(p)** China - CHTC-B. **(q)** Japan - JE05. **(r)** World - SORT.

Figure 4.2: Drive cycle acceleration v.s speed profiles.

The cumulative time duration of acceleration and deceleration for all the official bus cycles are shown in Figure 4.3. From this calculation it can be concluded that 80% of the accelerations are

13.6s or shorter, and 80% of the deceleration's are 11.5s or shorter.

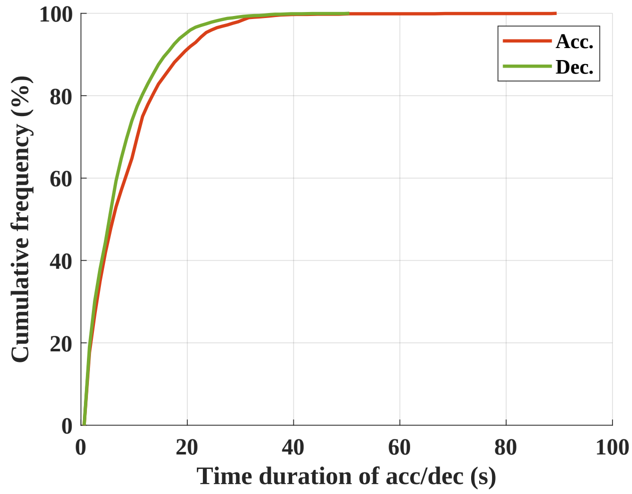


Figure 4.3: Cumulative time duration of acceleration and deceleration for all the official bus cycles.

4.2 Europe

In Europe, so far, no chassis-dynamometer cycle has ever been legislated for heavy duty vehicles, however there are legislative combustion engine dynamometer test cycles [117].

4.2.1 FIGE Transient Cycle (TC)

Developed year: Early 1990s

Developed by organization: FIGE Institute (Forschungsinstitut für Geräusche und Erschütterungen), Aachen, Germany, now TÜV Nord Group, Essen [117]

Developed for vehicle type: Heavy duty truck [119]

Based on: Measured vehicle speed from 17 goods vehicles and 3 public transport buses, during 3-4 days. FIGE is composed of truck operation on a flat road, under 80%-100% vehicle capacity operation [117].

Legislative? No, but it was used as a base for development of the European Stationary Cycle (ESC) and the European Transient Cycle (ETC) which were the legislative heavy duty engine-dynamometer cycles used during Euro III-V [117].

Cycle data reference: Dieselnet.com [120]

4.2.2 Germany - Braunschweig

The Braunschweigh cycle is also called 'Stochastischer Fahrzyklus für Stadtlinien Omnibusse'.

Developed year: mid 70s [117, Sec. 4.2.7.]

Developed by organization: Technical University of Braunschweig, Germany [117, Sec. 4.2.7.]

Developed for vehicle type: urban bus [117, Sec. 4.2.7.]

Based on: the US light duty cycle FTP-75, but with added stops, increased idling period and reduced top speed, and "there are 16 bus stops and 12 stops due to traffic conditions" [117, Sec. 4.2.7.] (the referred German final project report was not found)

Cycle data reference: Dieselnet.com [121]

4.2.3 UK - Millbrook London Transit Bus - MLTB

Developed year: 1996 [122]

Developed by organization: Transport for London and Millbrook Proving Ground Ltd [123]

Developed for vehicle type: Bus

Based on: logged data from a London Bus working on Route 159 from Streatham to Baker Street via Whitehall and Oxford Street [123]. The 'Inner London' part simulate a trip from Trafalgar Square to the end of Oxford Street, whereas the 'Outer' part simulate a trip from Brixton Station to Trafalgar Square [124].

Cycle data reference: Low Carbon Vehicle Partnership (LCVP), MS Excel-file [125]

4.2.4 UK - Tramaq Bus 01-10

During the project TRAMAQ (TRAffic Management and Air Quality) UG214 Vehicle operating profiles, 40 drive cycles were developed for 4 different vehicles, ten for each vehicle, in order to study speed profiles and emissions for different traffic management measures [126, 127].
Cycle 01-07 represent bus operation under various types of traffic management measures, whereas cycle 08-10 represent different traffic conditions without traffic management [126].

Table 4.2: Description of the 10 TRAMAQ cycles [128].

#	Traffic management measure/type
01	Traffic Calming - Speed Humps Cycle
02	Traffic Calming - Other Cycle
03	Bus Lane Cycle
04	Cycle Lane Cycle
05	Traffic Lights Cycle
06	One-way Cycle
07	Mini-roundabout Cycle Mini-roundabout Cycle
08	Control: Congested Cycle
09	Control: Non-congested Cycle
10	Control: Suburban Cycle

Developed year: 2000 [127]

Developed by organization: TRL Limited (Transport Research Laboratory), ordered by the Charging and Local Transport (CLT) Division of the Department for Transport (DfT) UK

Developed for vehicle type: Bus (and a car, a light and a heavy goods vehicle) [127]

Based on: measured speed data with both logger and GPS on 4 vehicle types (bus weight 6500-10 800 kg), in six sites in the UK [127]

Cycle data reference: email conversation with Department for Transport (DFT) UK [128]

4.3 USA

4.3.1 Manhattan Bus

Developed year: end of 1990's [129]

Developed by organization: The West Virginia University Transportable Heavy Duty Emissions Testing Laboratories [129]

Developed for vehicle type: low-speed urban transit bus [130, 117]

Based on: randomized micro-trips from logged driving patterns of transit bus (including hybrid-electric models) on Manhattan in New York City, USA [129]

Cycle data reference: Dieselnet.com [131]

4.3.2 New York Bus

Developed year: 1980s [132]

Developed by organization: US Environmental Protection Agency (EPA) [133]

Developed for vehicle type: Transit Bus in New York City [132], i.e. tough driving conditions with long time standing still and rapid accelerations and decelerations [117, Sec. 4.3.7.]

Based on: logged transit buses in New York City [132], from EPA's 1978 CAPE-21 survey [133]

Cycle data reference: Dieselnet.com [132]

4.3.3 Orange County (OC) Bus

Developed year: 2002 [130]

Developed by organization: The West Virginia University (WVU) [134]

Developed for vehicle type: intermediate-speed bus [117, Sec. 4.3.7.]

Based on: logged bus data in Los Angeles, USA [134]

Cycle data reference: Dieselnet.com [134]

4.3.4 HD UDDS

The cycle was criticized early on by vehicle manufacturers, for a large number of speed and acceleration fluctuations, resulting in unrealistic accelerator and brake pedal handling, and perhaps unreliable emission data [117, Sec. 4.3.4.].

Developed year: 1970s [117, Sec. 4.3.4.]

Developed by organization: Coordinating Research Council (CRC) and the U.S. EPA [117, Sec. 4.3.4.]

Developed for vehicle type: truck and bus (50/50 urban and highway)

Based on: statistically representative Mote Carlo model generated cycles from logged trucks (44+44) and buses (4+3) in New York and Los Angeles, with gross vehicle weights of at least 4530 kg [117, Sec. 4.3.4.]

Cycle data reference: Dieselnet.com [135]

4.3.5 Transit Coach Operating Duty Cycle (TCODC) or Business-Arterial-Commuter (BAC)

The Central Business District (CBD) part (SAE J1376) represent passenger boarding and exiting in the business district with frequent stops and a heavy traffic [133].

The Arterial part (SAE J1376) represent passenger boarding and exiting in less congested areas where traffic is lighter [133].

The Commuter (COM) part represent passenger boarding in a suburban area and transportated to a metropolitan area [133].

Developed year: used by EPA to measure fuel economy until 1997 [136]

Developed by organization: U.S. Department of Transportation and the Urban Mass Transit Association [117, Sec. 4.3.7.]

Developed for vehicle type: bus [133]

Based on: ...data not found...

Cycle data reference: Dieselnet.com [136]

4.4 Other Countries

4.4.1 Australia - CUEDC Me Diesel Bus >= 5 tonne

Developed year: 1998 [117, Sec. 2.4.]

Developed by organization: the Australian National Environment Protection Commission as part of the Diesel National Environment Protection Measure [137]

Developed for vehicle type: Bus (as well as 5 other vehicle types)

Based on: statistical micro-trip representation of 'congested', 'residential/minor', 'arterial' and 'freeway/highway' driving from 17 logged vehicles of different types, during normal driving in Sydney, comprised in a 30 min. cycle [117, Sec. 2.4.]

Cycle data reference: Dieselnet.com [137]

4.4.2 Japan - JE05 or ED12

Developed year: introduced in the emission standard 2005 [138] [117, Sec. 4.4.3.]

Developed by organization: the Japanese Ministry of Environment [117, Sec. 4.4.3.]

Developed for vehicle type: heavy vehicles with gross vehicle weight above 3500 kg [138]

Based on: represent Tokyo driving conditions [138]

Cycle data reference: Dieselnet.com [138]

4.4.3 China - CHTC

The China Heavy-Duty Commercial Vehicle Test Cycles (CHTC) include six chassis dynamometer driving cycles representing heavy commercial vehicles with gross vehicle weight from 3500 kg, for: city buses, inter-city coach buses, light trucks (< 5500 kg), heavy trucks (> 5500 kg), dump trucks and tractor trailers [139].

Developed year: released in October 2019 and adopted from May 2020 [139]

Developed by organization: China Automotive Technology Research Center (CATARC) [139]

Developed for vehicle type: City Buses

Based on: a part of the China automotive test cycle (CATC), which replaced the C-WTVC (a modified version of WHVC) for the purpose of vehicle certification [139]

Cycle data reference: Dieselnet.com [139]

4.5 World

4.5.1 World Harmonized Vehicle Cycle (WHVC)

Developed year: 1998-2001 [117, Sec. 4.5.1.],[140]

Developed by organization: UNECE GRPE [117, Sec. 4.5.1.]

Developed for vehicle type: Heavy duty vehicles (trucks & buses)

Based on: data from 65 different vehicles from Australia, Europe, Japan and USA. 9 light trucks, 20 rigid trucks, 18 trailer trucks and 11 public transport buses [140]

Legislative? No, but was used as a base for development of a new legislative engine-dynamometer test cycle for Euro VI since 2013 [117, Sec. 4.2]

Cycle data reference: Dieselnet.com [141]

4.5.2 SORT - (Standardized On-Road Test)

For on-road test of bus fuel consumption [142].
SORT 1: "heavy urban traffic, representative of Paris or London" [117, Sec. 4.2.7.]
SORT 2: "easy urban traffic, also called mixed traffic, e.g., in Madrid or Munich" [117, Sec. 4.2.7.]
SORT 3: "easy suburban traffic, e.g., Paris suburbs"[117, Sec. 4.2.7.]
The modules 1-3 can be combined as wished to represent desired average conditions [143].

Since 2017, there is also a test protocol called E-SORT for measuring traction energy consumption of full electric and plug-in hybrid electric buses [142].

Developed year: initiated 2000, final report 2004 [143]

Developed by organization: lead by the International Association of Public Transport or, Union Internationale des Transports Publics (UITP) [117, Sec. 4.2.7.] in collaboration with industrial partners such as public transport operators, manufacturers of vehicles and transmissions [144, 142]

Developed for vehicle type: urban buses [117, Sec. 4.2.7.]

Based on: compared to driving statistics from a large data base [144]

Legislative? No

Cycle data reference: from description in the brochure [144]

Chapter 5

Bus Drive Cycles - Logged in Gothenburg, Sweden

In June 2018, two similar electric buses with data as in Table 5.1, were added to line 16 in Gothenburg. Daytime they drove between the bus stops *Eriksbergstorget* and *Sahlgrenska Sjukhuset*, while during morning and afternoons they only ran between *Eriksbergstorget* and *Nordstan*.

By riding with these buses in regular traffic, their speed-time-traces have been logged using GPS loggers. Two different GPS loggers have been used: a Garmin GPSMAP 60CSx and Racelogic VBOX Sport, and their specifications are listed in Table 5.2.

Table 5.1: Specifications for the two similar commercial battery electric city buses on line 16 in Gothenburg, which was taken during logging of typical electric bus driving.

Bus parameter	**Value**	**unit**
Brand	Volvo	-
Model year	2018	-
Length	18557	mm
Width	2550	mm
Height	3300	mm
Curb weight	19585	kg
Total weight	28765	kg
Max. load weight	9180	kg
Number of axles	3	-
Tire dimension	275/70R22.5	-
Total number of passengers	135	-
Number of sitting passengers	38	-
Number of standing passengers	88	-
Electric motor power	370	kW

Table 5.2: Specifications for the used GPS loggers; Garmin GPSMAP 60CSx and Racelogic VBOX Sport.

	Garmin GPSMAP 60CSx	**Racelogic VBOX Sport**
Update frequency	1 Hz	20 Hz
Receiver dGPS	WAAS, EGNOS	yes
Map reference system	WGS84 or other	WGS84
Other sensors	Barometer (to calibrate height)	Temperature (internal)
Position accuracy (95% of time)	± 10 m	
Position accuracy dGPS	± 3-5 m (EGNOS)	± 5 m
Velocity accuracy	0.05 m/s, 0.18km/h	0.1 km/h, 0.0278 m/s
Velocity resolution	0.1km/h <v=1km/h> 1km/h	0.01 km/h
Acceleration accuracy		0.5%
Acceleration resolution		0.01 g (g=9.81 m/s^2)
Height accuracy (95% of time)	± 3 m	± 5 m
Height resolution	0.3 m	
Heading accuracy	± 5^o	± 0.2^o
Heading resolution	1^o	0.01^o
Log Output	Time, velocity Latitude, longitude, heading	Time, Velocity, height, vertical velocity Latitude, longitude, heading Number of satellites in fix Indication if dGPS is used Internal temperature, battery SOC
External antenna	Possible but not used	Possible and used

Unfortunately, the VBOX GPS suffered from several random data cut-outs during the logged time series, hence it would require tedious post signal processing to make the data useful. Therefore, since the Garmin GPS provided good enough data quality with a much lower demand for signal processing, the logs with the VBOX GPS were simply disregarded in favour of the ones logged with the Garmin GPS.

Out of all collected logs, four were of reasonable quality to be considered representative of electric bus driving in Gothenburg, Sweden; Log 1-4. Their routes on the map including bus stops are shown in Figure 5.1. Log 1 and 3 drove the same route in central Gothenburg (called A in Figure 5.1), as did log 2 and 4 (called B in Figure 5.1). The logs' speed-time series are shown in Figure 5.2, the acceleration as a function of speed are shown in Figure 5.3, and the cumulative driven distance are shown in Figure 5.4. Their characteristic data are presented in Table 5.3. The logs have rather similar characteristics, however log 4 has the highest max. speed, max. positive acceleration and RPA value, whereas log 2 has the lowest of the same parameters. Log 4 is also the longest driven cycle.

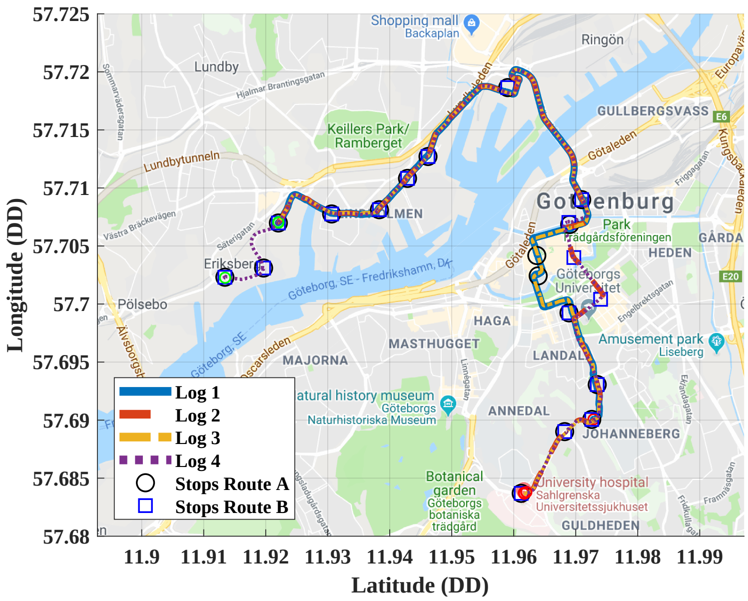


Figure 5.1: Geographical representation of the the four logged bus cycles, as well as marked bus stops, for two different routs of the same .

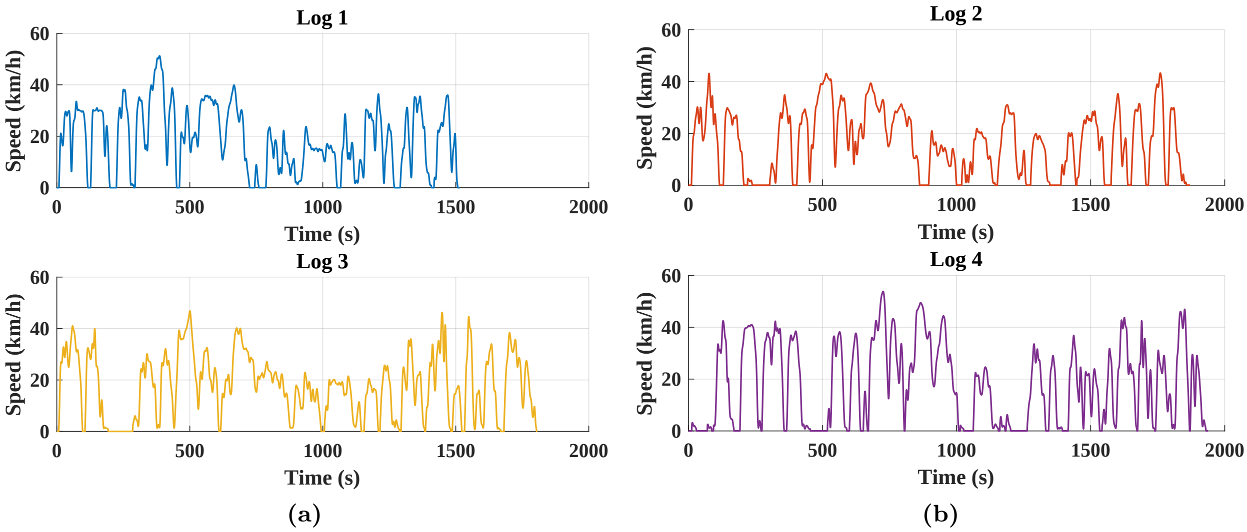


Figure 5.2: Speed as a function of time for the logged bus cycles.

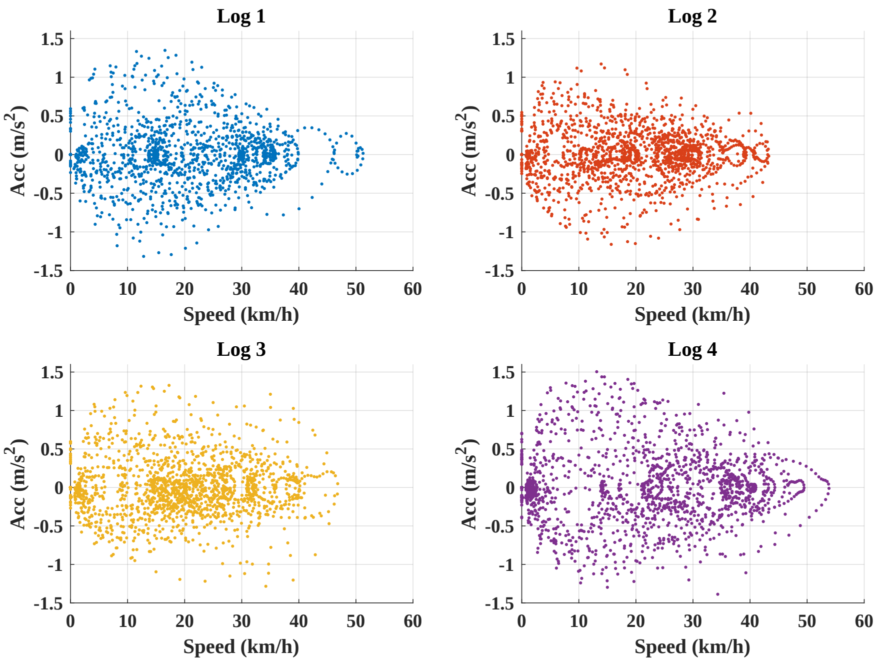


Figure 5.3: Acceleration as a function of Speed for the logged bus cycles.

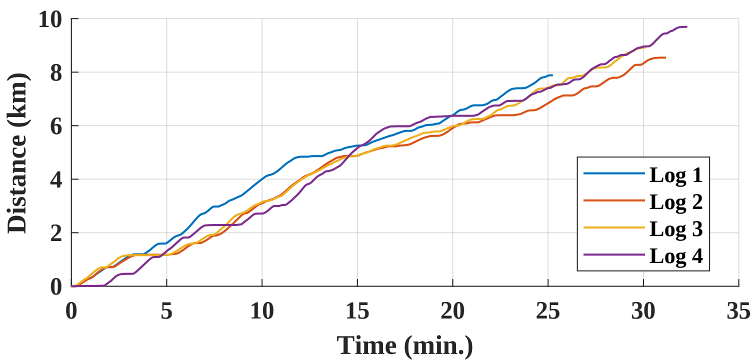


Figure 5.4: Distance as a function of time for the logged bus cycles.

Table 5.3: Logged bus drive cycles data summary.

Cycle	Log 1 Nrdvksgtn-CTH 2018-07-02	Log 2 Nrdvksgtn-Sahlgrnsk 2018-09-28	Log 3 Nrdvksgtn-Sahlgrnsk 2018-11-07	Log 4 Erksbtrgt-Sahlgrnsk 2018-10-05
Cycle duration (s)	1 515	1 871	1 807	1 938
Driven distance (m)	7 881	8 542	8 919	9 693
Max. speed (km/h)	51.3	43.3	46.8	53.8
Average speed (km/h)	18.7	16.4	17.8	18.0
Average running speed (km/h)	21.0	19.8	19.8	22.2
Std. speed (km/h)	12.5	12.2	12.0	15.4
Time share standing (%)	13.7	20.6	15.9	27.1
Time share <50 km/h (%)	85.4	79.4	84.1	72.2
Time share 50-80 km/h (%)	0.9	0.0	0.0	0.7
Time share > 80 km/h (%)	0.0	0.0	0.0	0.0
Max. pos. acc. (m/s²)	1.35	1.17	1.33	1.50
Max. neg. acc (m/s²)	-1.32	-1.16	-1.28	-1.39
Average pos. acc. (m/s²)	0.30	0.25	0.30	0.38
Average neg. acc. (m/s²)	-0.27	-0.24	-0.25	-0.32
Std. pos. acc. (m/s²)	0.29	0.22	0.28	0.35
Std. neg. acc. (m/s²)	0.25	0.23	0.22	0.28
Time share a<1 m/s² (%)	98.2	99.7	98.6	96.8
Time share 1<a<2 m/s² (%)	1.8	0.3	1.4	3.2
Time share 2<a<3 m/s² (%)	0	0	0	0
Time share a>3 m/s² (%)	0	0	0	0
Time share pos. acc. (%)	43	42	41	38
Time share neg. acc. (%)	48	43	50	45
No Acc.	78	77	83	77
No. Dec.	78	77	83	77
No Acc./dist. (#/km)	9.9	9.0	9.3	7.9
No. Dec./dist. (#/km)	9.9	9.0	9.3	7.9
RPA (m/s²)	0.13	0.11	0.13	0.16
Net climb (m)	40.6	37.4	33.4	34.0
Max. climb (m)	48.2	64.3	65.2	60.4
Max. pos. grade (%)	10.0	8.4	7.0	6.6
Max. neg. grade (%)	-4.5	-9.5	-6.0	-7.5
Average pos. grade (%)	2.1	1.8	1.9	1.7
Average neg. grade (%)	-1.3	-1.8	-1.4	-1.5
Std. pos. grade (%)	2.1	1.6	1.8	1.6
Std. neg. grade (%)	1.2	1.7	1.3	1.4
Time share grade<5 % (%)	93.7	97.2	97.5	98.3
Time share 5<grade<10 % (%)	6.3	2.8	2.5	1.7
Time share grade>10 % (%)	0	0	0	0
Time share pos. grade (%)	62	58	51	46
Time share neg. grade (%)	38	42	49	49
No Upp Hills	15	15	16	21
No. Down Hills	15	16	17	22
Upp Hills/dist. (#/km)	1.9	1.8	1.8	2.2
Down Hills/dist. (#/km)	1.9	1.9	1.9	2.3

The cumulative time duration of all accelerations and decelerations for all of the logged bus cycles combined, are shown in Figure 5.5, and separately in Figure 5.6. In the combined calculation, 80% of the accelerations are 13.9s or shorter, and 80% of the decelerations are 16.4s or shorter.

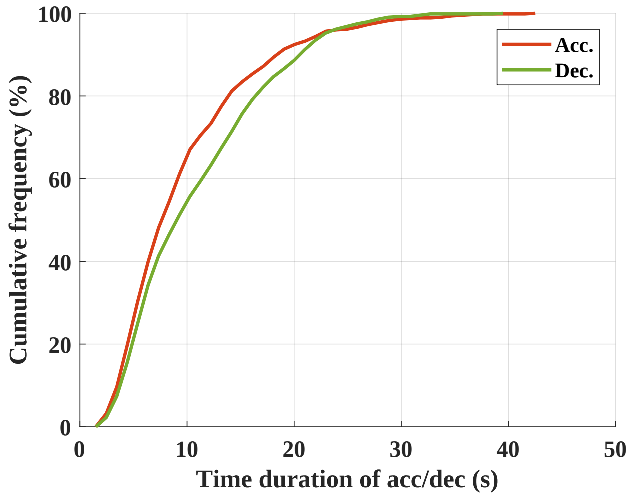


Figure 5.5: Cumulative time duration of acceleration and deceleration for all the logged bus cycles.

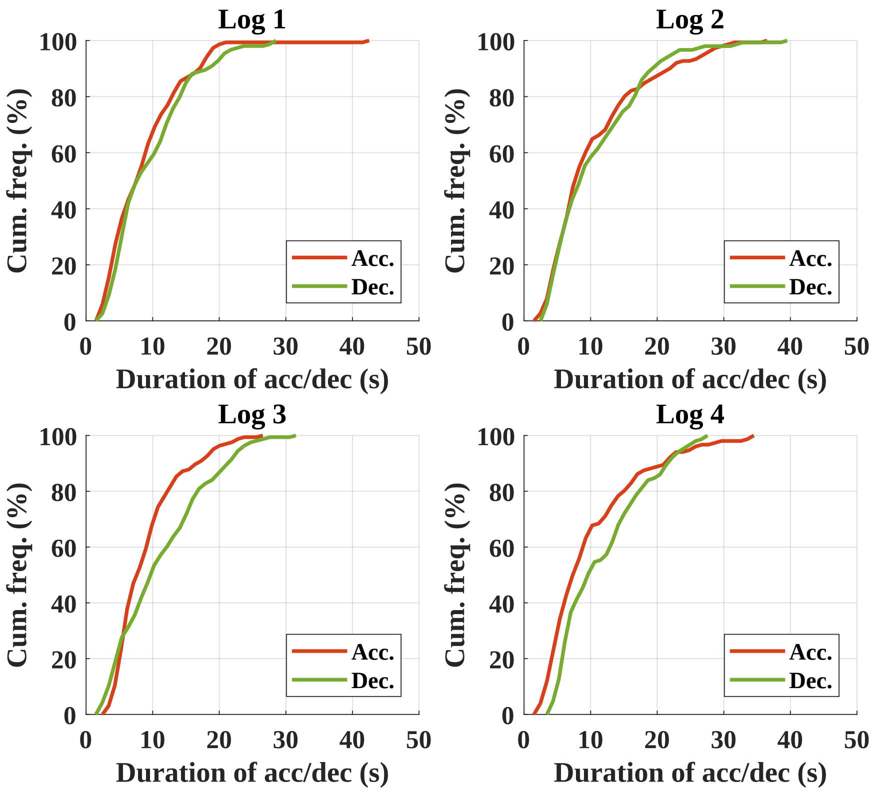


Figure 5.6: Cumulative time duration of acceleration and deceleration for the logged bus cycles separately.

Similarly, the cumulative time duration of all uphill and downhill driving for all of the logged bus cycles combined, are shown in Figure 5.5, and separately in Figure 5.6. In the combined calculation, 80% of the uphill drivings are 86.4s or shorter, and 80% of the downhill drivings are 70.4s or shorter.

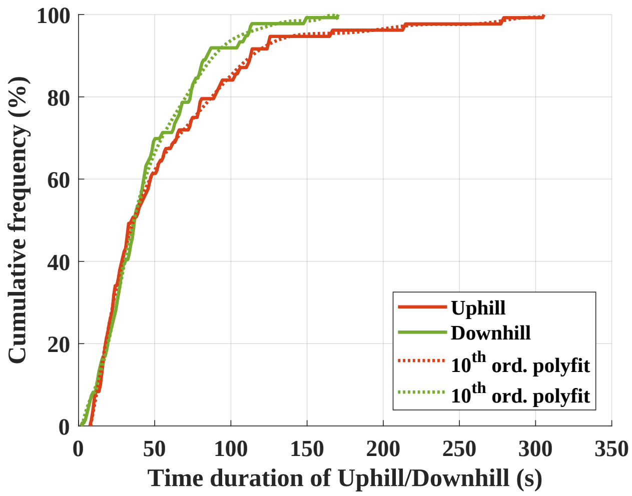


Figure 5.7: Cumulative time duration of uphill and downhill driving for all the logged bus cycles.

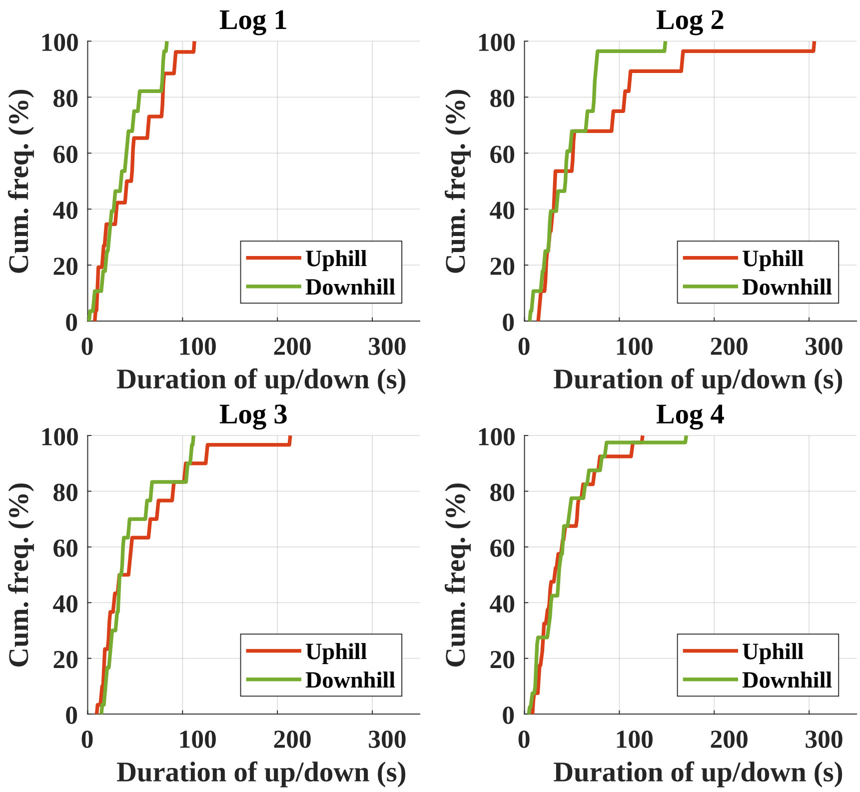


Figure 5.8: Cumulative time duration of uphill and downhill driving for the logged bus cycles separately.

Chapter 6

Bus Drive Cycle Energy Consumption

6.1 Commercial BECB Stated Energy consumption

Found data on energy consumption is stated in Table 2.2, along with its corresponding reference. This energy consumption data is also presented here, and it is complemented with found data on the drive cycle used, bus loading and whether air conditioner (AC) is on or off, as shown in Figure 6.1 and Table 6.1. The values **range** from **0.67-1.5 kWh/km** with a **mean** value of **0.97 kWh/km**.

For Bozankaya Sileo S10 a range of 0.65-0.75 kWh/km is given in the reference, hence in the table a mean value of 0.7 kWh/km is noted [19]. Similarily for Bozankaya Sileo S12 a range of 0.7-0.8 kWh/km is given, hence in the table a mean value of 0.75 is noted [20]. However, the driving conditions for the two Bozankaya models are not revealed. For Linkker Oy's Linkker 12+ LE, a general range of 0.8-1.2kWh/km is given for *"average commercial use"* [1].

For Chariot Motors buses, the SORT 2 cycle is stated as the driving condition [1].

Altoona is a laboratory test covering several drive cycles (HD-UDDS, Manhattan cycle, Orange County bus cycle, constant speed at 65 mph i.e. 105 km/h) in a specified sequence and possibly repeated if the bus's driving range allows it [145].

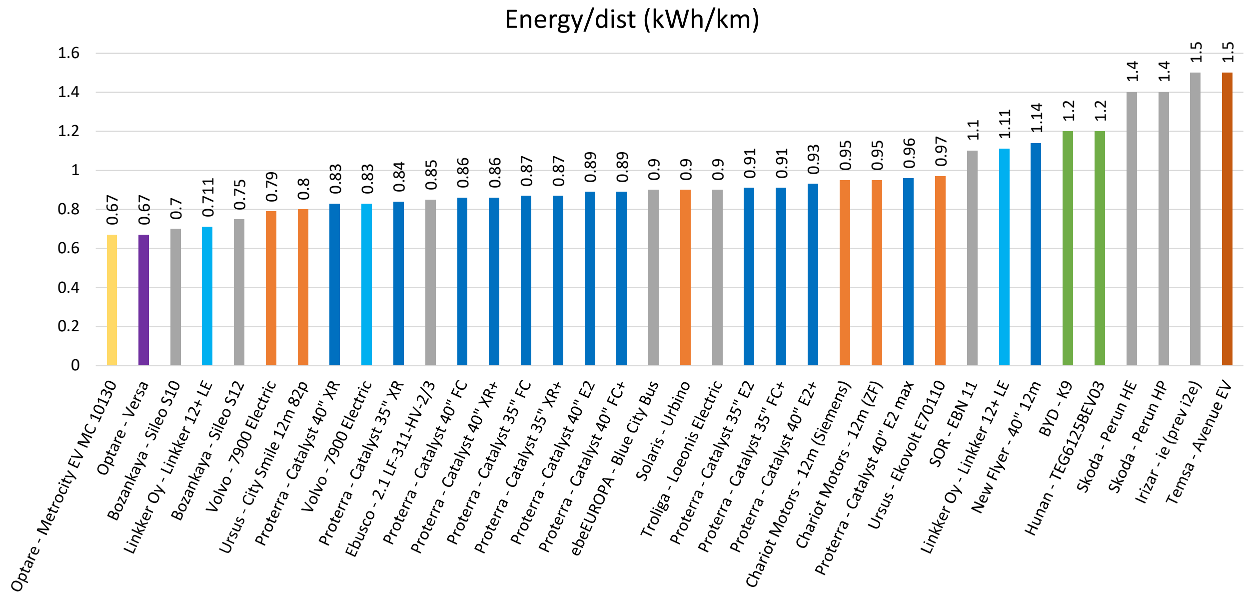


Figure 6.1: Energy consumption per distance (kWh/km) of commercial battery electric city buses 10-13m. References are given in Table 2.2. The bar colors correspond to the color coded drive cycles in Table 6.1. Gray color indicates that the drive cycle or condition is unknown.

Table 6.1: Energy consumption per distance of commercial battery electric city buses 10-13m, along with stated drive cycle, weight loading and AC status. References are given in Table 2.2.

Country code	Model	Energy/dist (kWh/km)	Drive Cycle	Load	AC On/off
Tr	Bozankaya - Sileo S10	0.7			
Tr	Bozankaya - Sileo S12	0.75			
CN	BYD - K9	1.2	city	Half	On
US	Chariot Motors - 12m (Siemens)	0.95	SORT 2		Off
US	Chariot Motors - 12m (ZF)	0.95	SORT 2		Off
DE	ebeEUROPA - Blue City Bus	0.9			
NL	Ebusco - 2.1 LF-311-HV-2/3	0.85			
CN	Hunan - TEG6125BEV03	1.2	City	Full	On
ES	Irizar - ie (prev i2e)	1.5			On
FI	Linkker Oy - Linkker 12+ LE	0.711	Braunschweig	2000kg	
FI	Linkker Oy - Linkker 12+ LE	1.11	Braunschweig	Full	
US	New Flyer - 40" 12m	1.14	Altoona		
GB	Optare - Metrocity EV MC 10130	0.67	London rute		
GB	Optare - Versa	0.67	York		
US	Proterra - Catalyst 35" E2	0.91	Altoona		Off
US	Proterra - Catalyst 35" FC	0.87	Altoona		Off
US	Proterra - Catalyst 35" FC+	0.91	Altoona		Off
US	Proterra - Catalyst 35" XR	0.84	Altoona		Off
US	Proterra - Catalyst 35" XR+	0.87	Altoona		Off
US	Proterra - Catalyst 40" E2	0.89	Altoona		Off
US	Proterra - Catalyst 40" E2 max	0.96	Altoona		Off
US	Proterra - Catalyst 40" E2+	0.93	Altoona		Off
US	Proterra - Catalyst 40" FC	0.86	Altoona		Off
US	Proterra - Catalyst 40" FC+	0.89	Altoona		Off
US	Proterra - Catalyst 40" XR	0.83	Altoona		Off
US	Proterra - Catalyst 40" XR+	0.86	Altoona		Off
CZ	Skoda - Perun HE	1.4			
CZ	Skoda - Perun HP	1.4			
PL	Solaris - Urbino	0.9	SORT 2		
cz	SOR - EBN 11	1.1			
TR	Temsa - Avenue EV	1.5	SORT 1		
SK	Troliga - Loeonis Electric	0.9			
PL	Ursus - City Smile 12m 82p	0.8	SORT 2		
PL	Ursus - Ekovolt E70110	0.97	SORT 2		
SE	Volvo - 7900 Electric	0.83	Braunschweig		
SE	Volvo - 7900 Electric	0.79	SORT 2		

6.2 Reference BECB Energy consumption During Official Drive Cycles

Using two identical reference electric machines as described in section 3.6, and letting them always work in parallel, the drive cycle energy consumption has been calculated. In order to also consider the losses in the transmission, inverter, and battery, their efficiencies are also included, but as fixed values for simplicity, with 97%, 97%, 99% respectively. A more detailed description of the modelling and calculations can be found in this project's final report *Elmaskiner för fordon i en cirkulär ekonomi* [146].

Compared to the method and results in [146], here one factor is different; the bus' mass during acceleration is multiplied with a so called *mass factor* of 1.1, i.e. an additional 10% weight is added that represent rotating masses e.g. tires, shafts, spur gears, electric machine rotors etc. The energy consumption reported here is therefore slightly higher compared to the figures reported in [146].

The calculated net battery energy consumption per driven distance of official drive cycles with the reference battery electric city bus, with a varied loading, is presented in Figure 6.2 and Table 6.2, in ascending order. With a gross weight of 18.4 tones and a curb weight of 13 tonnes, the full load is 5.4 tonnes. At no load, neither passenger nor driver weight are added to the bus' curb weight, whereas at full load the bus gross weight is used. In between, i.e. for 1/4, 1/2 and 3/4 load, a corresponding scaling of the full load weight is added to the curb weight during the calculations. Furthermore, the motors' total mass of 113 kg (56.6 kg per motor) is also added to the vehicle weight. No additional power consumption due to cooling/heating is included.

Gray color and absent result data in Table 6.2, indicates that at least one operating point of the drive cycle (with a time step of one second) is outside of the electric machines' operating area in motoring mode, hence the drive cycle result is omitted. Due to this, a total of 14 drive cycles were excluded from this comparison, since neither loading could fulfill all drive cycle operating points in motoring mode. Operating points outside of the machines operating area in generator mode are treated as friction braking, and thus do not lay ground for omitting the drive cycle result.

At **no load**, the values **range** from **0.65-0.95 kWh/km** with a **mean** value of **0.75 kWh/km**, whereas at **full load** they **range** from **0.90-1.21 kWh/km** with a **mean** value of **0.99 kWh/km**. These figures are well in line with officially stated energy consumption values for the commercial BECB in section 6.1; 0.67-1.5 kWh/km and a mean of 0.97 kWh/km.

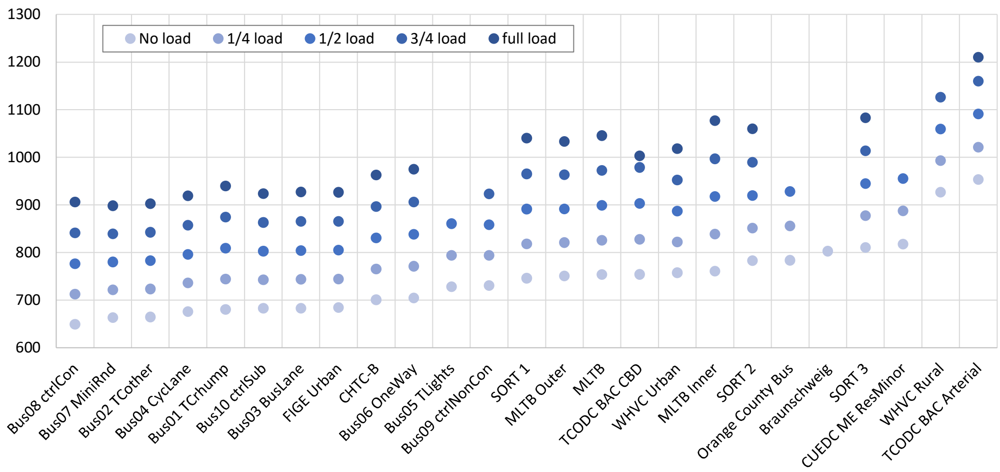


Figure 6.2: Calculated net battery energy consumption per driven official drive cycle distance (Wh/km) of the reference battery electric city bus during official drive cycles.

Table 6.2: Calculated net battery energy consumption per driven official drive cycle distance (Wh/km) of the reference battery electric city bus, in ascending order at no load. Gray color indicates that the at least one operating point of the drive cycle is outside of the motors' operating area.

Cycle Name	No load	1/4 load	1/2 load	3/4 load	full load
Bus08 ctrlCon	649.0	712.4	776.3	840.9	906.1
Bus07 MiniRnd	662.9	721.4	780.0	839.0	898.2
Bus02 TCother	664.2	723.3	782.7	842.3	902.3
Bus04 CycLane	675.7	736.1	796.2	857.4	919.0
Bus01 TCrhump	680.1	744.3	808.9	874.0	939.7
Bus10 ctrlSub	682.9	742.6	802.5	862.8	923.5
Bus03 BusLane	682.9	743.3	804.1	865.4	927.1
FIGE Urban	684.1	744.2	804.6	865.3	926.3
CHTC-B	700.4	765.2	830.5	896.4	963.0
Bus06 OneWay	704.4	770.9	838.1	906.0	974.8
Bus05 TLights	728.0	794.0	860.7		
Bus09 ctrlNonCon	730.4	793.9	858.1	922.9	
SORT 1	746.0	817.8	891.0	964.9	1040.2
MLTB Outer	750.8	820.8	891.6	963.2	1033.3
MLTB	753.6	825.7	898.8	972.5	1045.5
TCODC BAC CBD	753.9	827.4	903.1	978.7	1002.9
WHVC Urban	**757.4**	**821.9**	**887.0**	**952.1**	**1017.9**
MLTB Inner	760.6	838.4	917.6	996.6	1076.9
SORT 2	783.0	850.9	919.8	989.4	1060.0
Orange County Bus	783.6	855.6	928.0		
Braunschweig	802.6				
SORT 3	810.2	877.1	944.9	1013.3	1082.7
CUEDC ME ResMinor	817.7	887.4	955.4		
WHVC Rural	926.6	992.8	1059.4	1126.4	
TCODC BAC Arterial	953.1	1021.0	1090.8	1159.6	1209.8

6.3 Reference BECB Energy consumption During Logged Drive Cycles

The calculated net battery energy consumption per driven distance of the four logged drive cycles with the reference battery electric city bus, with a varied loading, is presented in Figure 6.3 and Table 6.3, in ascending order. The same calculation method as for the official drive cycles is used, except that here also the logged and estimated road grade is included in the calculations.

At **no load**, the values **range** from **0.83-0.88 kWh/km** with a **mean** value of **0.86 kWh/km**, whereas at **full load** only one of the drive cycles, Log 2, can be completely fulfilled by the reference electric machines, and it requires **1.18 kWh/km**.

When comparing max and mean speed as well as the RPA value of log 2 with the official drive cycles, the Tramaq *Bus04CycLane* cycle comes fairly close, however the energy consumption of Log 2 is 26%-28% higher. One possible reason could be the added energy consumption due to hill climbing in Log 2, whereas the road is considered flat in all official cycles.

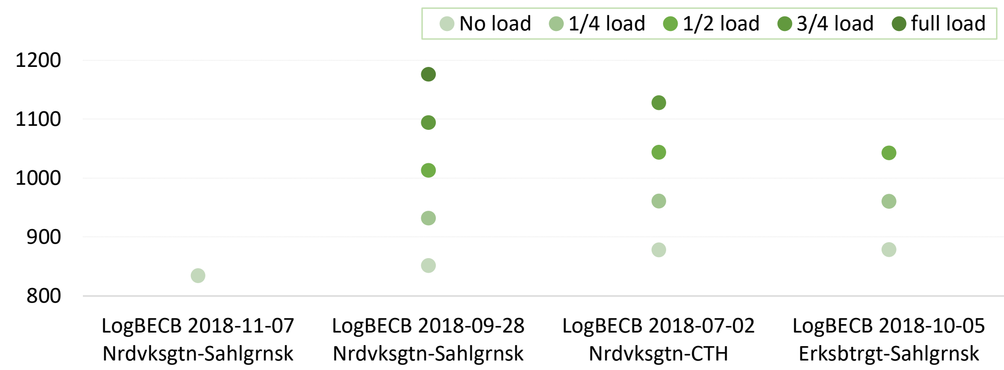


Figure 6.3: Calculated net battery energy consumption of reference battery electric city bus during logged drive cycles.

Table 6.3: Calculated net battery energy consumption of reference battery electric city bus, per driven logged drive cycle distance (Wh/km). Gray color indicates that the at least one operating point of the drive cycle is outside of the motors' operating area.

Log no.	Cycle Name	No load	1/4 load	1/2 load	3/4 load	full load
3	**LogBECB 2018-11-07 Nrdvksgtn-Sahlgrnsk**	834				
2	**LogBECB 2018-09-28 Nrdvksgtn-Sahlgrnsk**	852	932	1013	1094	1176
1	**LogBECB 2018-07-02 Nrdvksgtn-CTH**	878	961	1044	1128	
4	**LogBECB 2018-10-05 Erksbtrgt-Sahlgrnsk**	879	960	1043		

Bibliography

[1] (2018, Mar) Zeeus ebus report 2, an updated overview of electric buses in europe. Zero Emision Urban Bus System (ZeEUS), The International Association of Public Transport (UITP). Accessed 2018-10-17. [Online]. Available: http://zeeus.eu/uploads/publications/documents/zeeus-report2017-2018-final.pdf

[2] (2015, Aug) Number of daily passengers using bus rapid transit (brt) systems in 2015, by region. Statista.com. Accessed 2018-10-12. [Online]. Available: www.statista.com/statistics/561227/bus-rapid-transit-networks-worldwide-by-region-daily-ridership/

[3] (2017, Aug) Buses – global market trends, markets - competition – companies – key figures. SCI Verkehr GmbH. Accessed 2018-10-12. [Online]. Available: www.sci.de/fileadmin/user_upload/Flyer_MC_Bus.pdf

[4] (2017, July) Projected worldwide number of heavy-duty transit buses in 2015 and 2022, by region or country. Statista.com. Accessed 2018-10-12. [Online]. Available: www.statista.com/statistics/577547/forecast-for-global-number-of-transit-buses/

[5] (2017, June) Global ev outlook 2017. The International Energy Agency (IEA). Accessed 2018-10-15. [Online]. Available: www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf

[6] (2018, Jan) The european market for electric buses in 2017. Stefan Baguette, Group Market Analyst at Alexander Dennis Limited. Accessed 2018-10-15. [Online]. Available: www.linkedin.com/pulse/european-market-electric-buses-2017-stefan-baguette/?trk=join-al/

[7] A. T. Aleksandra O'Donovan, Senior Analyst. (2018, March) Electric buses in cities - driving towards cleaner air and lower co2. Bloomberg New Energy Finance, USA. Accessed 2018-10-16. [Online]. Available: https://data.bloomberglp.com/bnef/sites/14/2018/05/Electric-Buses-in-Cities-Report-BNEF-C40-Citi.pdf

[8] (2018, Oct) Production statistics. International Organization of Motor Vehicle Manufacturers (OICA). Accessed 2018-10-12. [Online]. Available: www.oica.net/production-statistics/

[9] (2016, Apr) Projected hybrid and electric heavy-duty transit bus* sales worldwide in 2022, by region or country. Statista.com. Accessed 2018-10-12. [Online]. Available: www.statista.com/statistics/577685/forecast-for-global-transit-bus-sales/

[10] (2016, Oct) Medium and heavy-duty electric commercial vehicle sales in north america and europe in 2025, by type. Statista.com. Accessed 2018-10-12. [Online]. Available: www.statista.com/statistics/712392/electric-medium-heavy-duty-commercial-vehicle-sales-in-key-regions/

[11] (2016, Oct) Navigant research forecasts battery-electric to be leading type of electric powertrain for buses through 2026. Green Car Congress.com. Accessed 2018-10-15. [Online]. Available: www.greencarcongress.com/2016/10/20161011-navigant.html

[12] (2019, March) Solaris ramping up electric bus market share. electrive.com, industry service for electric mobility. Accessed 2019-03-12. [Online]. Available: www.electrive.com/2019/03/09/solaris-strategy-aligns-for-ramping-up-market-share/

[13] (2017, Mar) Aptis, a new mobility experience. ALSTOM SA/NTL, France. Accessed 2018-10-17. [Online]. Available: http://www.newtl.com/wp-content/uploads/2017/03/aptis_product_sheet_march_17_en.pdf

[14] (2018, Jun) Electric bus series - hff6123g03ev-2. Ankai, China. Accessed 2018-06-04. [Online]. Available: http://english.ankai.com/HFF6123G03EV-2/index.htm

[15] (2018, Oct) Metro bus series - 12 mt full electric city bus. Avass, Australia. Accessed 2018-10-30. [Online]. Available: http://avass.com.au/e-products

[16] (2017, Aug) Full electric city bus. Avass Group, Australia. Accessed 2018-01-31. [Online]. Available: http://avass.com.au/key-executives

[17] (2016, Jun) Le bluebus 12 métres 100% électrique. Bolloré Blue Solutions, France. Brochure Accessed 2018-01-31.

[18] (2018, Oct) Germany, mannheim, primove, e-bus. Bombardier Transportation, Germany and Hess, Switzerland. Web page Accessed 2018-10-17. [Online]. Available: http://primove.bombardier.com/projects/europe/germany-mannheim-primove.htm

[19] (2018, Oct) Sileo: E-bus s10. Bozankaya, Turkey. Web page Accessed 2018-10-17. [Online]. Available: www.sileo-ebus.com/en/e-bus-models/e-bus-s10/

[20] (2018, Oct) Sileo: E-bus s12. Bozankaya, Turkey. Web page Accessed 2018-10-17. [Online]. Available: http://www.sileo-ebus.com/en/e-bus-models/e-bus-s12/

[21] (2018, May) Citymood 12 e | industria italiana autobus. BredaMenarinibus, Italy. Brochure Accessed 2019-02-21. [Online]. Available: www.industriaitalianaautobus.com/wp-content/uploads/2018/06/Scheda-Citymood-12E-2018.pdf

[22] (2018, Jan) Businova - electric bus - the range - pure electric. Businova, France. Web page Accessed 2018-10-17. [Online]. Available: http://www.businova.com/en/range/pure-electric.html

[23] (2013, Okt) Byd all-electric bus series - 12 m electric transit bus. BYD. Brochure Accessed 2018-01-31. [Online]. Available: http://www.byd.com/ap/images/ebus/download/k9%20brochure.pdf

[24] (2018, Okt) Byd electric buses, dimensions and weight. BYD Auto, Europe. Web page Accessed 2018-10-15. [Online]. Available: https://bydeurope.com

[25] (2017, Jul) K9 specs, byd coach specs. BYD, China. Brochures Accessed 2018-11-23. [Online]. Available: http://sg.byd.com

[26] (2018, Apr) The world's first 40-ft long-range battery-electric bus. BYD, USA. Brochure Accessed 2019-02-19. [Online]. Available: http://en.byd.com/usa/wp-content/uploads/2018/04/k9mc.pdf

[27] (2018, Oct) e.city gold. Caetano, Portugal. Brochure Accessed 2018-11-27. [Online]. Available: http://caetanobus.pt/wp-content/uploads/2018/10/e.City-Gold.pdf

[28] (2018, Oct) e.city gold. Caetano Bus, Portugal. Web page Accessed 2018-11-27. [Online]. Available: https://caetanobus.pt/en/buses/e-city-gold/

[29] (2018, Oct) 12 m hub drive by zf, 12 m central drive by siemens. Chariot Motors, USA. Web page Accessed 2018-10-17. [Online]. Available: https://chariot-electricbus.com/products/electric-vehicles/

[30] (2019, Feb) Eq6810cacbev/eq6810cacbev1 pure electric city bus. Dongfeng Automobile Company DFAC, China. Web page Accessed 2019-02-18. [Online]. Available: http://www.dfxylxc.com/kechezhanshi/keyunkeche/1148.html

[31] R. Braun and T. Lidle. (2017, May) Elektroantrieb im Öpnv im ländlichen raum erfarhrungen aud dem hohenlohekreis 20. energitag bingen. Nahverkehr Hohenlohekreis NVH. Presentation Accessed 2017-09-21. [Online]. Available: http://www.ebe-europa.com/wp-content/uploads/2015/09/BLUE-CITY-BUS-Datenblatt-Stand-11002015.pdf

[32] (2015, Sep) Technische beschreibung blue city bus – 12m. ebe EUROPA, Menningen, Germany. Web page Accessed 2019-03-11. [Online]. Available: http://www.ebe-europa.com/wp-content/uploads/2015/09/BLUE-CITY-BUS-Datenblatt-Stand-11002015.pdf

[33] (2016, Oct) Driven by innovation, dutch 100% electric city bus with a full day range. Ebusco, Netherlands. Brochure Accessed 2018-10-17. [Online]. Available: www.elektromobilitaet.nrw.de/fileadmin/Daten/Download_Dokumente/Veranstaltungen/2016_Workshop_E-Busse_Vortr%c3%a4ge/Busworkshop_20161005_Busproduzent__EBUSCO.pdf

[34] (2017, Aug) Ebusco 2.1 - 100% electric 12 meter 3-door city bus service manual. Ebusco, Netherlands. Manual Accessed 2018-10-17. [Online]. Available: https://ebusco.eu/app/uploads/Service-Manual-Ebusco-2.1.pdf

[35] (2015, Oct) Ekova electron. Ekova Electric a.s., Czech Republic. Brochure Accessed 2019-02-21. [Online]. Available: https://ekova.cz/uploads/assets/d8997020-c99c-4359-8233-a1c1b4a9a39a.pdf

[36] (2017, Apr) Golden dragon electric bus xml6125cle. Golden Dragon, China. Web page Accessed 2019-02-04. [Online]. Available: http://www.goldendragonbus.com/news/272819.html

[37] (2018, Oct) Electric bus series. Golden Dragon, China. Web page Accessed 2018-10-15. [Online]. Available: http://www.goldendragonbus.com/car/view/11153.html#pro-d03

[38] (2016, Nov) Ev350 all electric transit bus. Green Power, Canada. Brochure Accessed 2018-10-15. [Online]. Available: http://www.greenpowerbus.com/EV350SpecSheet-Jan19-2016.pdff

[39] (2018, Oct) Green power bus. Green Power, Canada. Web page Accessed 2018-10-15. [Online]. Available: www.greenpowerbus.com/product-line/#heavyduty

[40] (2019, Feb) Electric bus. Guangtong Auto, China. Web page Accessed 2019-02-18. [Online]. Available: http://guangtongauto.zhyle.com/list-1-1.html

[41] (2016, May) Gx elec. Heuliez Bus, France. Presentation Accessed 2018-10-17. [Online]. Available: http://assises-territoriales.businesscatalyst.com/assets/gx_elec_presentation_03062015.pdf

[42] (2018, Nov) Klq6125gev. Higer, China. Web page Accessed 2018-11-11. [Online]. Available: http://en.higer.com/newenergy/121.html

[43] (2018, Oct) Ev mode city bus. Hunan CRRC, China. Web page Accessed 2018-10-17. [Online]. Available: www.crrcgc.cc/en/g9377/s13975/t264632.aspx

[44] (2017, Jun) Technical data for: Haw 12 lelf, 18 lelf, hcb 12 lelf. Hybricon Bus System, Sweden. Brochure Accessed 2018-02-01. [Online]. Available: http://www.hybricon.se/en/products--services/electric-buses/haw-gen2.htm

[45] (2018, Oct) ie 10 m, 12 m, 18 m. Irizar, Spain. Web page Accessed 2018-10-17. [Online]. Available: www.irizar.com/en/autobuses-y-autocares/autobuses/autobuses-electricos

[46] (2019, Feb) ie 10 m, 12 m, 18 m. King Long, China. Web page Accessed 2019-02-18. [Online]. Available: http://www.king-long.com/5-new-energy-bus/

[47] (2018, Oct) Technology. Linkker Oy, Finland. Web page Accessed 2018-10-17. [Online]. Available: http://www.linkkerbus.com/technology/

[48] (2018, Nov) World premiere of the mercedes-benz ecitaro. Daimler, Germany. Web page Accessed 2018-11-28. [Online]. Available: www.daimler.com/innovation/case/electric/ecitaro-2.html

[49] (2018, Jul) The new ecitaro, technical information. Mercedes Benz, Germany. Brochure Accessed 2019-02-18. [Online]. Available: www.mercedes-benz-bus.com/sv_SE/buy/services-online/download-technical-brochures.html#container_copy/content/element_385184368

[50] (2018, Aug) xcelsior charge, 35' electric bus. New Flyer, USA. Brochure Accessed 2018-10-15. [Online]. Available: www.newflyer.com/site-content/uploads/2018/09/One-Pager-Tech-Spec_XE35_2018_NF.pdf

[51] (2017, Sep) xcelsior. New Flyer, USA. Brochure Accessed 2018-10-15. [Online]. Available: www.newflyer.com/site-content/uploads/2017/09/729-NFL-Xcelsior-Final.pdf

[52] (2017, Oct) Electric bus competitive comparison. New Flyer, USA. Brochure Accessed 2018-11-26. [Online]. Available: www.newflyer.com/site-content/uploads/2017/10/Xcelsior-CHARGE-Competitive-Comparison.pdf

[53] (2018, Nov) Specifications, solo, metrocity, versa, metrodecker. Optare, Turkey. Brochures Accessed 2018-11-26. [Online]. Available: http://www.optare.com/vehicles/

[54] (2017, Sep) Catalyst, 35 foot bus. Proterra, USA. Brochures Accessed 2018-01-31. [Online]. Available: www.proterra.com/wp-content/uploads/2017/10/PROTERRA_SPEC-SHEET_35FT_9.28.17.pdf

[55] (2017, Sep) Catalyst, 40 foot bus. Proterra, USA. Brochures Accessed 2018-01-31. [Online]. Available: www.proterra.com/wp-content/uploads/2017/10/PROTERRA_SPEC-SHEET_40FT_9.28.17-1.pdf

[56] (2018, Nov) E60, e80, e120. Rampini, Italy. Web page Accessed 2018-11-26. [Online]. Available: www.rampini.it/it/autobus-mezzi-speciali_4/categorie/e-bus-hydrogen-bus-trasporto-pubblico-urbano_1/

[57] (2018, Nov) E120 elettrico. Rampini, Italy. Brochure Accessed 2018-11-26. [Online]. Available: www.rampini.it/upload/E120%20ITA-1547111242898-281.pdf

[58] (2018, Jan) Trolley, battery bus. Škoda, Czech Republic. Brochure Accessed 2018-10-17. [Online]. Available: www.skoda.cz/data/catalog/6/72/3813.pdf

[59] (2016, Nov) Městský nízkopodlažní bateriový autobus Škoda perun hp. Škoda, Czech Republic. Brochure Accessed 2018-10-17. [Online]. Available: www.skoda.cz/data/catalog/6/72/2740.pdf

[60] (2019, Feb) Njl6100bev product details. Skywell Nanjing Golden Dragon, China. Web page Accessed 2019-02-05. [Online]. Available: www.skywellcorp.com/en/index.php/product/detail/5.html

[61] (2019, Feb) Njl6100bev. chinacar.com, China. Web page Accessed 2019-02-18. [Online]. Available: www.chinacar.com.cn/diandongche/car/523.html

[62] (2018, Oct) Alternative powertrain, product catalogue 2018. Solaris, Poland. Brochure Accessed 2018-11-26. [Online]. Available: www.solarisbus.com/public/assets/content/strona-glowna/EN_Napdy_alternatywne_2018_-_wersja_elektroniczna.pdf

[63] (2018, Sep) Sor ns 12 electric. SOR, Czech Republic. Brochure Accessed 2018-10-17. [Online]. Available: www.sor.cz/wp-content/uploads/2017/09/NS_12_electric_ANG_LoRes.pdf

[64] (2018, Sep) Sor ebn 8, ebn 9,5, ebn 11. SOR, Czech Republic. Brochure Accessed 2018-11-26. [Online]. Available: www.sor.cz/wp-content/uploads/2017/09/EBN_8-95-11_ANG_LoRes.pdf

[65] (2018, Sep) Avenue electron. Temsa, Turkey. Brochure Accessed 2019-03-01. [Online]. Available: www.temsa.com/UserFolder/en/pdf/AVENUE-ELECTRON-fuar.pdf

[66] (2019, Mar) Leonis electric. Troliga, Slovakia. Web page Accessed 2019-03-01. [Online]. Available: http://troligabus.sk/leonis-electric/

[67] (2017, May) Ursus bus. Ursus, Poland. Brochure Accessed 2018-10-17. [Online]. Available: www.ursus.com/files/katalog_produktow/prospekt-Ursus-Bus-PL.pdf

[68] (2018, Nov) Citea, technical specifications. VDL, Netherlands. Web page Accessed 2018-11-27. [Online]. Available: www.vdlbuscoach.com/Producten/Openbaar-vervoer/Citea-The-E-Worker/technische-specificaties.aspx

[69] (2015, Jun) Volvo electric concept bus. Volvo Group, Sweden. Brochure Accessed 2018-06-11. [Online]. Available: www.electricitygoteborg.se/sites/default/files/content/PDF/volvo_electric_concept_bus_se.pdf

[70] (2016, Mar) Volvo 7900 electric. Volvo Group, Sweden. Brochure Accessed 2017-03-20. [Online]. Available: www.volvobuses.se/content/dam/volvo/volvo-buses/master/bre/our-offering/documents/Volvo-7900-Electric-Brochure-SE-2016.pdf

[71] (2019, Feb) Pure electric. Wuzhoulong, China. Web page Accessed 2019-02-21. [Online]. Available: www.wzlmotors.cn/en/products.aspx

[72] (2018, Oct) 11, 12 meters pure electric city bus, pure electric beijing dang dang bus. YinLong, China. Web page Accessed 2018-10-22. [Online]. Available: http://zhyle.com/en/sohw-1275.html

[73] (2019, Feb) Zk6105bevg. Yutong Bus, China. Web page Accessed 2019-02-04. [Online]. Available: https://en.yutong.com/products/ZK6105BEVG-Asia.shtml

[74] (2018, Oct) Model e12. Yutong Bus, Scandinavia. Web page Accessed 2018-10-15. [Online]. Available: http://yutongeurobus.se/products/model-e12-2/#tab-id-2

[75] (2018, Oct) Electric city bus, electric coach. Zhongtong Bus, China. Web page Accessed 2018-10-15. [Online]. Available: http://zhongtongbuses.com/10-2-electric-city-bus/

[76] (2016, Jun) Le minibus 100% électrique. Bolloré Blue Solutions, France. Brochure Accessed 2018-10-17. [Online]. Available: www.blue-solutions.com/wp-content/uploads/2018/05/2-Fiches-techniques_EXE_V3-1.pdf

[77] (2017, Nov) 12m battery-electric bus. BYD Europe B.V., Netherlands. Brochure Accessed 2018-10-15. [Online]. Available: http://bydeurope.com/downloads/eubs_specification/BYD_12_Meters_Electric_bus.pdf

[78] (2015, Apr) New energy bus series. Xiamen Golden Dragon, China. Brochure Accessed 2018-10-15. [Online]. Available: http://www.goldendragonbus.com/car/view/11153.html#pro-d03

[79] (2018, Aug) xcelsior charge, 40' electric bus. New Flyer, USA. Brochure Accessed 2018-10-15. [Online]. Available: www.newflyer.com/site-content/uploads/2018/09/One-Pager-Tech-Spec_XE40_2018_NF.pdf

[80] (2016, Nov) Dvounápravový 12 m bateriový autobus Škoda perun he. Škoda, Czech Republic. Brochure Accessed 2018-10-17. [Online]. Available: www.skoda.cz/data/catalog/6/72/2740.pdf

[81] (2018, Jun) E12 full electric city bus, iice12 full electric intercity bus. Yutong Bus, China. Web page Accessed 2018-06-04. [Online]. Available: http://en.yutong.com/z/newenergybus

[82] (2018, Jun) Zhongtong bus lck6122evg electric bus. Chinabuses.org. Web page Accessed 2018-06-04. [Online]. Available: www.chinabuses.org/product/buses/815.html

[83] (2018, Nov) Världspremiär för mercedes-benz ecitaro och emobility system. Mercedes Benz, Sweden. Web page Accessed 2018-11-28. [Online]. Available: www.mercedes-benz/content/sweden/mpc/mpc_sweden_website

[84] (2018, Nov) Tm4 sumo md. TM4, Canada. Web page Accessed 2018-11-08. [Online]. Available: www.tm4.com/products/direct-drive-electric-powertrain/sumo-md/

[85] (2019, Feb) Citea electric, technical specifications. VDL, Netherlands. Web page Accessed 2019-02-28. [Online]. Available: www.vdlbuscoach.com/Producten/Openbaar-vervoer/Citea-The-E

[86] (2011, Mar) Elfa components data sheets. Siemens, Germany. Brochure Accessed 2018-10-17. [Online]. Available: https://w3.usa.siemens.com/drives/us/en/electric-drives/hybrid-drives/automotive/Documents/elfa-components-data-sheets.pdf

[87] (2018, Nov) Product overview, axle & transmission systems for buses & coaches. ZF Friedrichshafen AG, Germany. Accessed 2019-02-01. [Online]. Available: www.zf.com/products/media/product_media/buses_1/product_overview_1/product_overview_axle_transmission_systems.pdf

[88] (2016, Sep) Byd electric vehicles. BYD, China. Presentation Accessed 2019-03-05. [Online]. Available: www.theicct.org/sites/default/files/BYDEVSEDEMA.pdf

[89] (2018, Sep) Electric commercial vehicles. Siemens, Germany. Brochure Accessed 2019-03-18. [Online]. Available: https://www.energycolombia.org/wp-content/uploads/3.Siemens-Eduardo-Cando.pdf

[90] (2015, Oct) Za wheel. Ziehl-Abegg, Germany. Brochure Accessed 2019-03-15. [Online]. Available: http://donar.messe.de/exhibitor/metropolitansolutions/2016/H535810/broschuere-zawheel-00703157-en-screen-ger-459453.pdf

[91] (2016, Jul) Za wheel - produktvorstellung. Ziehl-Abegg, Germany. Presentation Accessed 2019-02-01. [Online]. Available: www.ludwig-wahl.de/wp-content/uploads/2016/08/Exkursion_Elektromobilit%C3%A4t_ZAwheel_Produktvorstellung_DE-2016-07-04.pdf

[92] (2018, Oct) Ursus city smile. Ursus, Poland. Web page Accessed 2018-10-17. [Online]. Available: www.ursus.com/en/product/ursus-city-smile-10#basic-information

[93] (2017, Oct) Za wheel. Ziehl-Abegg, Germany. Brochure Accessed 2019-10-03. [Online]. Available: www.ziehl-abegg.com/fileadmin/Downloadcenter_NEW/00_englisch%28EN%29_MASTER/X01_Brochures_Flyers/Flyer-ZAwheel.pdf

[94] (2018, Aug) Direct-drive electric powertrain systems. TM4, Canada. Brochure Accessed 2018-11-09. [Online]. Available: www.tm4.com/wp-content/uploads/2018/08/TM4-SUMO-Product-Brochure.pdf

[95] (2017, Jan) Tm4 electrodynamic systems. TM4, Canada. Presentation Accessed 2018-11-09. [Online]. Available: www.shandongbusiness.gov.cn/public/attachment/kindeditor/file/20170401/01c9be65166ede528ef0e0531532e9ad.pdf

[96] (2015, Jan) Sumo, electric powertrain systems for medium & heavy duty vehicles. TM4, Canada. Brochure Accessed 2018-11-08. [Online]. Available: www.tm4.com/wp-content/uploads/2013/12/TM4_SUMO-Datasheet1.pdf

[97] (2018, Nov) Tsa motor for trolley, hybrid and electric buses. TSA Traktionssysteme, Austria. Web page Accessed 2018-11-09. [Online]. Available: https://tsa.at/references/tsa_motor_for_trolley_hybrid_and_electric_buses_1

[98] (2019, Feb) Pure power system. Wohan, China. Web page Accessed 2019-02-19. [Online]. Available: http://www.wutep.com/cdlxt/index.jhtml

[99] (2015, Apr) Pure electric buses, the only way. BYD Europe, China. Brochure Accessed 2019-03-05. [Online]. Available: http://bydeurope.com/downloads/download.php?filename=ebus-brochure-s.pdf

[100] R. Xiong, H. He, and F. Sun, "Methodology for optimal sizing of hybrid power system usingparticle swarm optimization and dynamic programming," *Energy Procedia, Elsevier*, vol. 75, pp. 1895–1900, 2015, clean, Efficient and Affordable Energy for a Sustainable Future: The 7th International Conference on Applied Energy (ICAE2015). [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1876610215009455

[101] H. Tian, S. E. Li, X. Wang, Y. Huang, and G. Tian, "Data-driven hierarchical control for online energy management of plug-in hybrid electric city bus."

[102] W. Wang, H. Pan, C. Lin, J. Yi, and S. Yang, "A dual-motor coupling propulsion system design and control strategy optimization for an electric coach," February 2019.

[103] C. Zheng, Z. LiYan, S. Yong, M. ZiLin, and H. ZongQi, "Multi-objective parameter optimization for a single-shaft series-parallel plug-in hybrid electric bus using genetic algorithm," *SCIENCE CHINA, Technological Sciences*, vol. 59, no. 8, pp. 1176–1185, August 2016.

[104] L. Zhang, X. Hu, Z. Wang, F. Sun, J. Deng, and D. G. Dorrell, "Multiobjective optimal sizing of hybrid energy storage system for electric vehicles," *IEEE Transactions on Vehicular Technology*, vol. 67, no. 2, pp. 1027–1035, 2018.

[105] J. WANG, Q. N. WANG, P. Y. WANG, J. N. WANG, and N. W. ZOU, "Hybrid electric vehicle modeling accuracy verification and global optimal control algorithm research," vol. 16, no. 3, pp. 513–524, 2015.

[106] M. Hirz. (2015, July) Automotive engineering, focus: Basics of longitudinal vehicle dynamics. Institute of Automotive Engineering, Graz University of Technology. Conference: Automotive WorkshopAt: Tongji University, School of Automotive Studies. [Online]. Available: www.researchgate.net/publication/280303367_Basics_of_longitudinal_vehicle_dynamics

[107] M. Dou, G. Wu, C. Shi, and X. Liu, "Modeling and identification of longitudinal responses of an electric vehicle for drivability improvement," vol. 9, no. 4, February 2013.

[108] N. Lin, C. Zong, and S. Shi, "The method of mass estimation considering system error in vehicle longitudinal dynamics," *Energies, MDPI*, vol. 12, no. 1, 2019. [Online]. Available: https://www.mdpi.com/1996-1073/12/1/52

[109] X. Wu, J. Du, C. Hu, and T. Jiang, "The influence factor analysis of energy consumption on all electric range of electric city bus in china," in *2013 World Electric Vehicle Symposium and Exhibition (EVS27)*, Nov 2013, pp. 1–6.

[110] H. Jianyao, X. Huawei, H. Zhiyuan, H. Linyi, and L. Qunxing, "Study on braking force distribution based on fuzzy control algorithm," in *2015 IEEE Advanced Information Technology, Electronic and Automation Control Conference (IAEAC)*, Dec 2015, pp. 1114–1119.

[111] S. Gaogao, P. Xinfu, O. Changjie, and L. Shi, "The method of parameter design for the powertrain system of city hybrid electric public bus based on srm," in *2011 International Conference on Electric Information and Control Engineering*, April 2011, pp. 5517–5520.

[112] F. Wang, H. Zhong, Z. Ma, J. Wang, X. Mao, and B. Zhuo, "Operation coordinated control for a dual electric machines hybrid electric bus," in *2008 IEEE Vehicle Power and Propulsion Conference*, Sept 2008, pp. 1–3.

[113] M. Khodabakhshian, J. Wikander, and L. Feng, "Fuel efficiency improvement in hevs using electromechanical brake system," in *2013 IEEE Intelligent Vehicles Symposium (IV)*, June 2013, pp. 322–327.

[114] C. Pronovost. (2014, Jun) Market research on hybrid architectures for city bus. TM4Electrodynamic Systems). Accessed 2018-11-09. [Online]. Available: http://emc-mec.ca/wp-content/uploads/TS3_5_MARKET-RESEARCH-ON-HYBRID-ARCHITECTURES-FOR-CITY-BUS_CPronovost.pdf

[115] "Senior research engineer," Pär Ingelström, Volvo Group Trucks Technology, Jun 2018, personal correspondence.

[116] E. A. Grunditz, S. T. Lundmark, M. Alatalo, T. Thiringer, and A. Nordelöf, "Three traction motors with different magnet materials — influence on cost, losses, vehicle performance, energy use and environmental impact," in *2018 Thirteenth International Conference on Ecological Vehicles and Renewable Energies (EVER)*, April 2018, pp. 1–13.

[117] E. G. Giakoumis, *Driving and Engine Cycles. [electronic resource].* Cham : Springer International Publishing : Imprint: Springer, 2017.

[118] E. A. Grunditz, "Design and assessment of battery electric vehicle powertrain, with respect to performance, energy consumption and electric motor thermal capability," Thesis for the Degree of Doctor of Philosophy, Chalmers University of Technology, 2016. [Online]. Available: http://publications.lib.chalmers.se/records/fulltext/236616/236616.pdf

[119] F. Zhen, N. N. Clark, C. R. Bedick, M. Gautam, W. S. Wayne, G. J. Thompson, and D. W. Lyons, "Development of a heavy heavy-duty diesel engine schedule for representative measurement of emissions," *Journal of the Air & Waste Management Association*, vol. 59, no. 8, pp. 950–959, 2009. [Online]. Available: https://doi.org/10.3155/1047-3289.59.8.950

[120] (2018, Sept) European transient cycle (etc) fige. Dieselnet. Accessed 2018-09-21. [Online]. Available: www.dieselnet.com/tech/cycles/etc_fige.txt

[121] (2018, Sept) Braunschweig city driving cycle. Dieselnet. Accessed 2018-09-20. [Online]. Available: www.dieselnet.com/tech/cycles/braunschweig.txt

[122] (2020, Dec) Bus emissions test cycle development. Millbrook UK. Accessed 2020-12-30. [Online]. Available: www.millbrook.co.uk/services/propulsion-systems-testing/vehicle-emissions-testing/bus-emissions-test-cycle-development/

[123] (2018, Sept) Testing & accreditation (lceb certification). LowCVP UK. Accessed 2018-10-11. [Online]. Available: www.lowcvp.org.uk/initiatives/lceb/lceb-testing.htm

[124] (2011, Feb) Vehicle accreditation requirements, low carbon emission buses. LowCVP UK. Accessed 2018-10-08. [Online]. Available: www.lowcvp.org.uk/ugc-1/1/2/0/vehicle_certification_requirements.pdf

[125] (2003, May) Millbrook london transport bus (mltb) drive cycle. LowCVP UK. MS Excel-file, Accessed 2018-10-04. [Online]. Available: www.lowcvp.org.uk/ugc-1/1/2/0/mltb-test-cycle.xls

[126] P. B. S. Latham and T. Barlow. (2005, Feb) The effect of traffic management schemes on emissions from heavy-duty vehicles, published project report ppr038. TRL Limited. Accessed 2018-09-21. [Online]. Available: https://trl.co.uk/sites/default/files/PPR038.pdf

[127] J. M. Green and T. J. Barlow. (2004, Mar) Traffic management and air quality: realistic driving cycles for traffic management schemes - prepared for charging and local transport division, department for transport, trl report trl596. TRL Limited. Accessed 2020-12-30. [Online]. Available: http://trl.demo.varistha.co.uk/uploads/trl/documents/TRL596.pdf

[128] "Project tramaq ug 214 vehicle speed profiles, received through personal communication via e-mail," Department for Transport (DfT) UK, Feb 2003, accessed 2018-09-28.

[129] D. L. McKain, N. Clark, T. H. Balon, P. J. Moynihan, S. A. Lynch, and T. C. Webb, "Characterization of emissions from hybrid-electric and conventional transit buses," in *CEC/SAE Spring Fuels Lubricants Meeting Exposition*. SAE International, jun 2000. [Online]. Available: https://doi.org/10.4271/2000-01-2011

[130] *Recommended Practice for Measuring Fuel Economy and Emissions of Hybrid-Electric and Conventional Heavy-Duty Vehicles*, sep 2002. [Online]. Available: https://doi.org/10.4271/J2711_200209

[131] (2018, Sept) Manhattan bus cycle. Dieselnet. Accessed 2018-09-20. [Online]. Available: https://dieselnet.com/standards/cycles/manhattan.php

[132] (2018, Sept) New york bus. Dieselnet. Accessed 2018-09-20. [Online]. Available: https://dieselnet.com/standards/cycles/nybus.php

[133] (2021, Jan) Drivecat: Drive cycle analysis tool. National Renewable Energy Laboratory (NREL), founded via the United States Department of Energy (USDOE). Accessed 2021-01-05. [Online]. Available: https://www.nrel.gov/transportation/drive-cycle-tool/

[134] (2018, Sept) Orange county bus (oc bus) cycle. Dieselnet. Accessed 2018-09-20. [Online]. Available: https://dieselnet.com/standards/cycles/ocbus.php

[135] (2020, Oct) Epa urban dynamometer driving schedule (udds) for heavy-duty vehicles. Dieselnet. Accessed 2020-10-02. [Online]. Available: https://dieselnet.com/standards/cycles/udds.php

[136] (2018, Oct) Transit coach operating duty cycle (bac). Dieselnet. Accessed 2018-09-21. [Online]. Available: https://dieselnet.com/standards/cycles/bac.php

[137] (2018, Oct) Cuedc (diesel) - australia. Dieselnet. Accessed 2018-09-21. [Online]. Available: https://dieselnet.com/standards/cycles/cuedc.php

[138] (2018, Oct) Japanese je05 cycle. Dieselnet. Accessed 2018-10-10. [Online]. Available: https://dieselnet.com/standards/cycles/jp_je05.php

[139] (2021, May) China heavy-duty commercial vehicle test cycle (chtc). Dieselnet. Accessed 2021-05-17. [Online]. Available: https://dieselnet.com/standards/cycles/chtc.php

[140] H. Steven. (2001, April) Development of a worldwide harmonised heavy-duty engine emissions test cycle, final report. ECE-GRPE WHDC Working Group, TRANS/WP29/GRPE/2001/2. Accessed 2020-09-07. [Online]. Available: http://www.unece.org/fileadmin/DAM/trans/doc/2001/wp29grpe/TRANS-WP29-GRPE-42-inf02.pdf

[141] (2018, Sept) World harmonized vehicle cycle (whvc). Dieselnet. Accessed 2018-09-20. [Online]. Available: www.dieselnet.com/tech/cycles/whvc.txt

[142] (2020, Dec) Uitp sort e-sort brochures. The International Association of Public Transport (UITP). Accessed 2018-10-30. [Online]. Available: www.uitp.org/publications/uitp-sort-e-sort-brochures/

[143] (2004, Sep) Uitp project 'sort', standardised on-road test cycles. The International Association of Public Transport (UITP), Brussels, Belgium. Accessed 2018-10-30. [Online]. Available: http://mohamedmezghani.com/images/stories/site/Brochures/5SORT-2004-ENG.pdf

[144] (2014, Jul) Uitp project 'sort', standardised on-road test cycles. The International Association of Public Transport (UITP), Brussels, Belgium. Accessed 2018-10-30. [Online]. Available: https://ruter.no/globalassets/kollektivanbud/moter/dialogmoter-buss/2014-09-26-bussanbud/2014-10-03-volvo-en_brochure.pdf?id=2679

[145] (2017, Oct) Altoona bus testing and research center test bus procedure. The Thomas D. Larson Pennsylvania Transportation Institute, The Pennsylvania State University, USA. Accessed 2019-05-29. [Online]. Available: www.altoonabustest.psu.edu/assets/docs/bus%20docs/updated%20procedures/Energy-Economy1.pdf

[146] A.-M. Tillman, A. Nordelöf, E. Grunditz, S. Lundmark, M. Alatalo, T. Thiringer, and M. Ljunggren. (2020, Nov) Elmaskiner för fordon i en cirkulär ekonomi, report no. 2020:06. Institutionen För Teknikens Ekonomi Och Organisation, Chalmers University of Technology, Sweden. Accessed 2021-05-19. [Online]. Available: www.energimyndigheten.se/forskning-och-innovation/projektdatabas/sokresultat/?projectid=25485

[147] (2017, July) Fact sheet - buses in figures. European Automobile Manufacturers Association (ACEA). Accessed 2018-10-12. [Online]. Available: www.acea.be/uploads/publications/factsheet_buses.pdf

[148] (2018, May) Acea report, vehicles in use, europe 2017. European Automobile Manufacturers Association (ACEA). Accessed 2018-10-12. [Online]. Available: www.acea.be/uploads/statistic_documents/ACEA_Report_Vehicles_in_use-Europe_2017.pdf

[149] M. Chediak. (2018, Feb) Electric buses will take over half the world fleet by 2025. Bloomberg New Energy Finance, USA, news. Accessed 2018-10-15. [Online]. Available: www.bloomberg.com/news/articles/2018-02-01/electric-buses-will-take-over-half-the-world-by-2025

[150] (2019, Feb) High end new energy bus, f8, a8s. Anyuan Bus Manufacture, China. Web page Accessed 2019-02-18. [Online]. Available: www.ayvip.com/en/

[151] (2019, Feb) Electric bus model 420 (vitovt electro), model 433 (vitovt max electro). Belkommunmash, Belarus. Web page Accessed 2019-02-21. [Online]. Available: https://bkm.by/en/catalog/elektrobusy/

[152] (2016, Jun) Le minibus 100% électrique. Bolloré Blue Solutions, France. Brochure Accessed 2018-01-31.

[153] (2018, Oct) Sileo: E-bus s18. Bozankaya, Turkey. Web page Accessed 2018-10-17. [Online]. Available: http://www.sileo-ebus.com/en/e-bus-models/e-bus-s18/

[154] (2018, Oct) Sileo: E-bus s25. Bozankaya, Turkey. Web page Accessed 2018-10-17. [Online]. Available: http://www.sileo-ebus.com/en/e-bus-models/e-bus-s25/1of

[155] (2019, Feb) 18m battery-electric bus. BYD, Europe. Web page Accessed 2019-02-19. [Online]. Available: www.bydeurope.com/vehicles/ebus/types/18.php

[156] (2017, Apr) Modulo ultra-lightweight electric city bus. Evopro, Hungary. Brochure Accessed 2018-10-17. [Online]. Available: www.evopro.hu/hu/termekek/kompozit-jarmuvek/hajtas-es-elektronika-fejlesztes/Modulo_final_EN_web.pdf

[157] (2018, Oct) What is modulo? Evopro, Hungary. Web page Accessed 2018-10-17. [Online]. Available: http://modulo.hu/

[158] (2019, Feb) Bj6180. Foton, China, TM4, Canada. Web page Accessed 2019-02-04. [Online]. Available: http://auv.foton.com.cn/en/models.php?id=32&cid=65&mid=76

[159] (2015, May) First 18-meter electric bus in china powered by tm4 sumo hd powertrain with external rotor motor technology. Green Car Congress. Web page Accessed 2018-11-27. [Online]. Available: https://www.greencarcongress.com/2015/05/20150507-tm4.html

[160] (2017, Jun) Ev250 all-electric transit bus. Green Power, Canada. Brochure Accessed 2018-11-23. [Online]. Available: http://www.greenpowerbus.com/wp-content/uploads/2017/10/EV250v1.pdf

[161] (2018, Aug) Atak elecric. Karsan, Turkey. Brochure Accessed 2019-03-13. [Online]. Available: www.karsan.com.tr/download/files/atak_electric_katalog_260718_7133425643.pdf

[162] (2019, Jan) Jest elecric. Karsan, Turkey. Brochure Accessed 2019-03-13. [Online]. Available: www.karsan.com.tr/download/files/jest-electric_9796932936.pdf

[163] (2018, May) xcelsior charge, 60' electric bus. New Flyer, USA. Brochure Accessed 2018-10-15. [Online]. Available: www.newflyer.com/site-content/uploads/2018/05/Xcelsior-CHARGE-XE60-Specification-Sheet.pdf

[164] (2019, Feb) Doruk elecra. Otokar, Turkey. Web page and Brochure Accessed 2019-02-21. [Online]. Available: www.otokar.com.tr/tr/urunler/doruk-electra-otobus

[165] (2019, Mar) Bus de 7m, 9m. PVI, France. Web page Accessed 2019-03-13. [Online]. Available: www.pvi.fr/oreos-2x,009.html

[166] (2011, Oct) Market leader in electric industrial vehicles, electric driveline l. PVI, France. Brochure Accessed 2019-03-13. [Online]. Available: www.pvi.fr/IMG/pdf/PVI_Driveline_L.pdf

[167] (2011, Oct) Market leader in electric industrial vehicles, electric driveline xl. PVI, France. Brochure Accessed 2019-03-13. [Online]. Available: http://pvi.nouveauxterritoires.fr/IMG/pdf/PVI_Driveline_XL.pdf

[168] C. Tekgül. (2016, Apr) Temsa, smart mobility. Director of Marketing and Business Development, Temsa, Turkey. Presentation Accessed 2018-11-27. [Online]. Available: www.busandcoach.travel/download/Busworld2016/temsa_smart_mobility.pdf

[169] (2016, May) City, freedom of movement. Temsa, Turkey. Brochure Accessed 2018-11-27. [Online]. Available: www.temsa.com/UserFolder/en/pdf/City_%C4%B0ngilizce.pdf

[170] (2016, Mar) Md 9 electricity. Temsa, Turkey. Brochure Accessed 2018-11-27. [Online]. Available: www.temsa.com/UserFolder/de/pdf/City_Almanca.pdf

[171] (2018, Jun) Fordonsuppgifter, (specific vehicle specifications based on registration). Transportstyrelsen, Sweden. Wep page Accessed 2018-06-27. [Online]. Available: www.electricitygoteborg.se/sites/default/files/content/PDF/volvo_electric_concept_bus_se.pdf

[172] (2017, Nov) Irizar e-mobility, turnkey integral mobility solutions. Irizar, Spain. Brochure Accessed 2019-02-26. [Online]. Available: http://www.irizar.com/en/descargas/catalogos/irizar-i2e-catalogo/

[173] (2018, Jun) Electric bus series - hff6101k10ev. Ankai, China. Accessed 2018-06-04. [Online]. Available: http://english.ankai.com/HFF6101K10EV/index.htm

[174] (2017, Aug) Full electric touring coach. Avass Group, Australia. Accessed 2018-01-31. [Online]. Available: http://avass.com.au/key-executives

[175] (2018, Oct) Touring coach series - 9.5 mt full electric coach. Avass, Australia. Accessed 2018-10-30. [Online]. Available: http://avass.com.au/metro-bus

[176] (2019, Feb) 13m battery-electric coach. BYD, Europe. Web page Accessed 2019-02-19. [Online]. Available: www.bydeurope.com/vehicles/ebus/types/13.php

[177] (2019, Feb) Dongfeng electric bus eq6100clbev2 manufactured by dongfeng motor corporation. Dongfeng, China. Web page Accessed 2019-02-18. [Online]. Available: http://dongfeng.su/en/auto/eq/dongfeng-eq6100clbev2.html

[178] (2015, Mar) Kayoola solar bus. Kayoola, Uganda. Brochure Accessed 2019-02-21. [Online]. Available: http://kiiramotors.com/new/wp-content/uploads/Kayoola%20Solar%20Bus%20V10%20Magazine.pdf

[179] (2019, Feb) Nanjing jinlong njl6118bev bus (pure electric 24-49 seat). chinabuses.com, China. Web page Accessed 2019-02-18. [Online]. Available: https://m.chinabuses.com/product/buses/12471.html

[180] (2019, Feb) 2014 njl6118bev. Nanjing Jinlong Bus Manufacturing, China. Web page Accessed 2019-02-18. [Online]. Available: www.d1ev.com/news/shichang/35930

[181] (2019, Feb) 11 meters, 24-51 shenlong pure electric bus slk6118ale0bevs6. chinacar.com, China. Web page Accessed 2019-02-18. [Online]. Available: http://www.chinacar.com.cn/keche/shenlong_3385/SLK6118ALE0BEV

[182] (2019, Feb) The 100% electric city bus. Astonbus, USA. Web page Accessed 2019-02-18. [Online]. Available: http://astonbususainc.yolasite.com/

[183] (2019, Feb) Jxk6840b. Bonluck Bus, China. Web page Accessed 2019-02-18. [Online]. Available: www.bonluckbus.com/products_detail/productId=220.html

[184] (2019, Feb) Dancerbus. Dancerbus, Lithuania, Germany. Web page Accessed 2019-02-18. [Online]. Available: http://dancerbus.com/

[185] (2019, Feb) Epv. EPV, USA. Web page Accessed 2019-02-18. [Online]. Available: www.epvcorp.com/history/

[186] (2019, Feb) Alfa bus. Jiangsu Alfa Bus, China. Web page Accessed 2019-02-18. [Online]. Available: https://alfabus.en.china.cn/

[187] (2014, Feb) Mhi to supply 2 electric buses featuring high-performance mlix lithium-ion rechargeable batteries for zero emissions transportation system in kitakyushu city. Mitsubishi Heavy Industries, Japan. Web page Accessed 2019-02-18. [Online]. Available: https://www.mhi.com/news/story/1402141772.html

[188] (2019, Feb) Products and services. TECNOBUS, Italy. Web page Accessed 2019-02-18. [Online]. Available: https://www.tecnobus.it/index.php/en/products-services

[189] (2020, Oct) Citywide electric. Scania, Sweden. Web page Accessed 2020-10-01. [Online]. Available: https://www.scania.com/group/en/home/products-and-services/buses-and-coaches/citywide-bev.html

Appendix A

Bus Statistics

A.1 Total number of buses in use

The number of buses (regardless of energy storage and propulsion technology) that were in use globally in 2016 is shown in Table A.1[1]. The data is provided by the German market analysis consultancy company SCI in [3]. The figures for the number of buses in Europe were also compared to data provided by the European Automobile Manufacturers Association (ACEA) in [147, 148], which declare slightly lower figures compared to SCI (and even internally contradicting). The conclusion is that the presented numbers should be considered as rough estimations.

An additional aim is to indicate the number of buses per region. For example, it can be seen that almost half of the buses were used in Asia.

Table A.1: Buses in use globally in 2016 [3].

	Numbers	**Share of total**
Asia	5 017 000	48%
CIS	1 419 000	14%
North America	1 401 000	13%
Europe	1 013 000	10%
South, Central America	920 000	9%
Africa, Middle East	555 000	5%
Australia, Pacific	118 000	1%
Total	**10 443 000**	

Statista projects a large increase in the number of buses all over the world until 2022 compared to 2015, especially in Russia, South America, and India, as shown in Table A.2.

[1]CIS stand for the Commonwealth of Independent States, and includes Azerbaijan, Armenia, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Turkmenistan, Uzbekistan and Ukraine

Table A.2: City/urban buses (>9 m and >8 tonnes in gross vehicle weight) in use 2015 and projected 2022 [4].

Region/Country	**2015**	**2022**	**Share 2015**	**Share 2022**
China	41 300	57 700	37%	29%
India	18 900	36 400	17%	18%
South America	13 700	30 800	12%	15%
Europe	11 900	16 000	11%	8%
Russia	5 100	14 200	5%	7%
North America	5 200	6 900	5%	3%
Other markets	15 000	39 000	14%	19%
Total	111 000	201 000		

A.2 Total Annual Bus Production

Annual bus production by region is shown in Figure A.1, where the data is provided by The International Organization of Motor Vehicle Manufacturers (OICA) [8]. It can be seen that the vast majority of the buses were produced in Asia and Oceania.

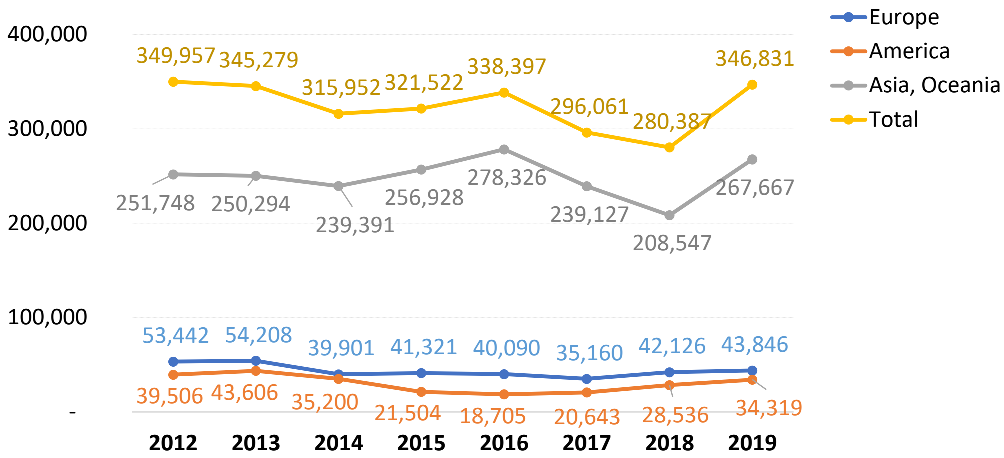


Figure A.1: Annual bus production per year and per region [8].

A.3 Daily Bus Passengers

The number of daily bus passengers in 2015 per region are shown in Figure A.1 based on data from Statista[2] [2]. The number of daily travellers were the highest in Latin America.

[2]MENA countries consist of Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, United Arab Emirates and Yemen

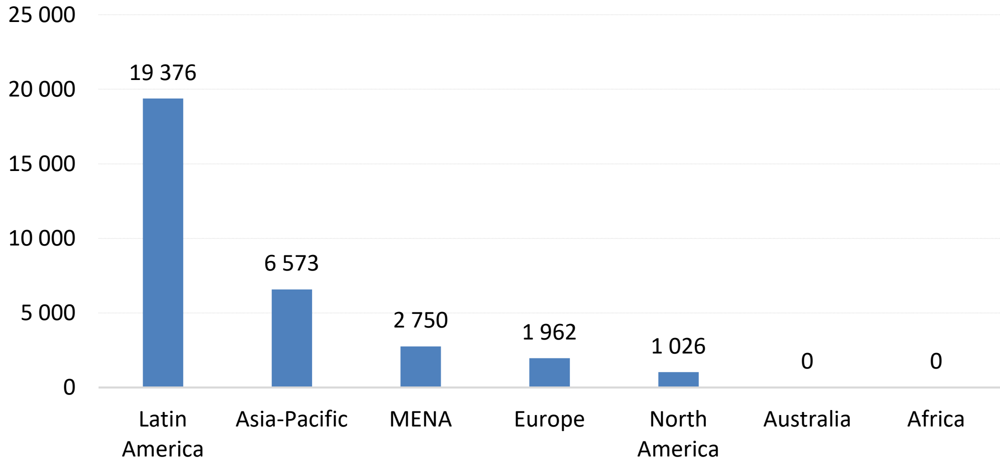


Figure A.2: The daily number of bus passengers in 1000s per region 2015 [2].

A.4 Annual Electric bus sales

A.4.1 Europe

According to data collected and presented by Stefan Baguette (Market Analyst and Product Manager at Alexander Dennis Limited), the annual number of electric bus orders in Europe 2017 is presented in Figure A.3 [6]. The number of ordered battery electric buses has increased each year, and has posed the largest share of the four types covered since 2013, although not shown here but in the source.

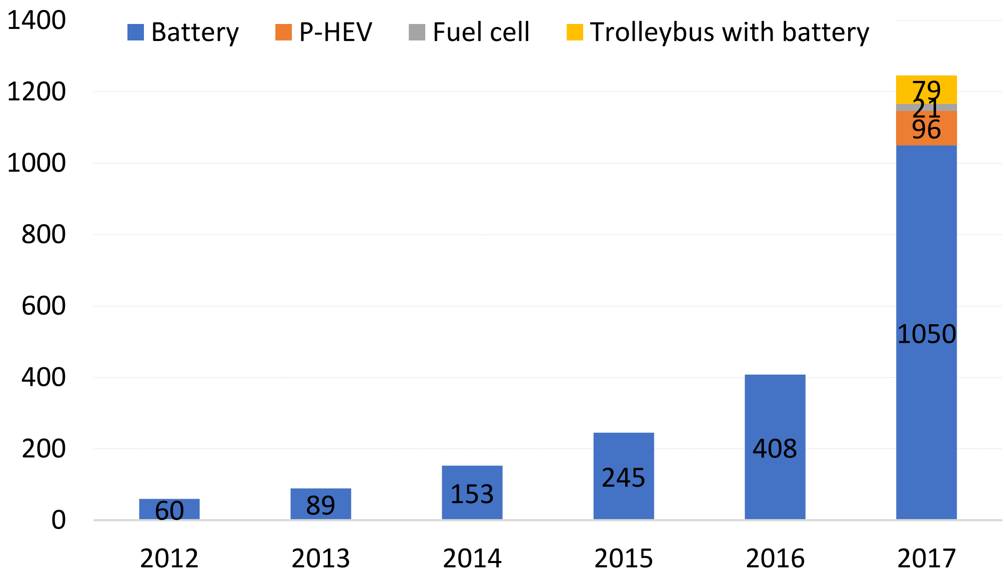


Figure A.3: Electric bus orders in Europe 2017 [6].

A.4.2 China

The annual sales of electric buses in China as by Bloomberg [7], is presented in Figure A.4.

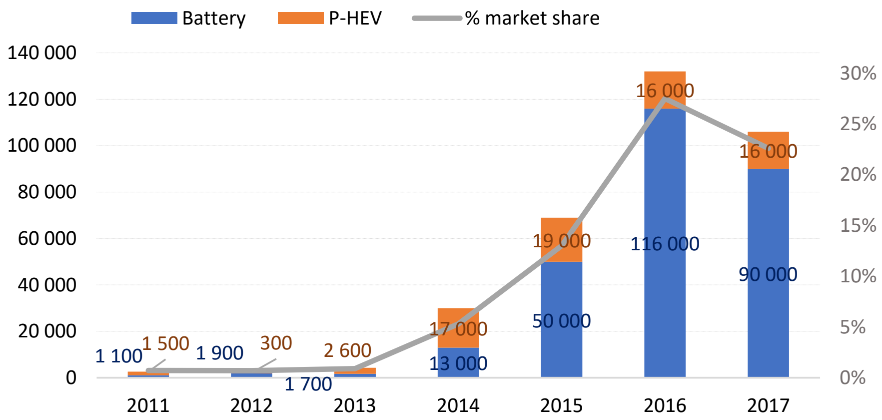


Figure A.4: The annual sales of electric buses in China as by Bloomberg [7], separated into battery electric and plug-in hybrid electric drivetrains, including their total market share.

A.5 Electric Bus Fleet

A.5.1 World

The global electric bus stock and per region in 2016, is shown in Table A.3, as declared in IEA's *Global EV Outlook 2017* [5]. Based on the text in [5], both battery and plug-in electric buses are likely included and not differentiated. China clearly dominated the market for electric buses in 2016.

Table A.3: Global electric bus stock and per region 2016 [5].

	Numbers	**Share of Global total**
China	343 500	99.6%
Europe	1 273	0.4%
USA	200	0.1%
Global total	345 000	

A.5.2 Europe

According to data collected and presented by Stefan Baguette (Market Analyst and Product Manager at Alexander Dennis Limited), the electric bus fleet in Europe by country 2017 is presented in Figure A.5 [6]. Countries with less than 50 electric buses are excluded. The data shown here include delivered as well as ordered buses. The top four countries were Great Britain, the Netherlands, France and Poland.

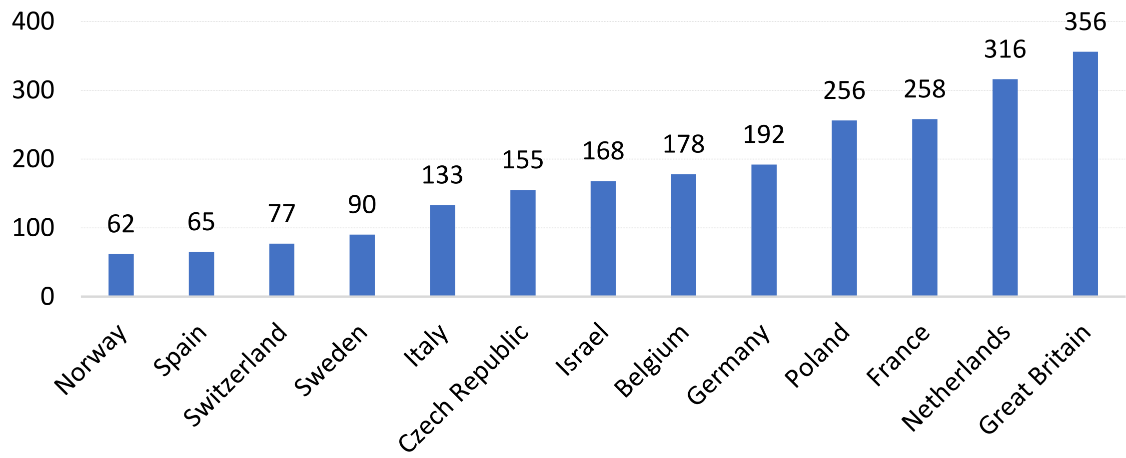


Figure A.5: European electric bus fleet by country 2017 [6].

For the same year as above, 2017, the data collected by Bloomberg regarding electric bus fleet in Europe is seen in Figure A.6 [7]. The top three countries were the United Kingdom, Germany and the Netherlands.

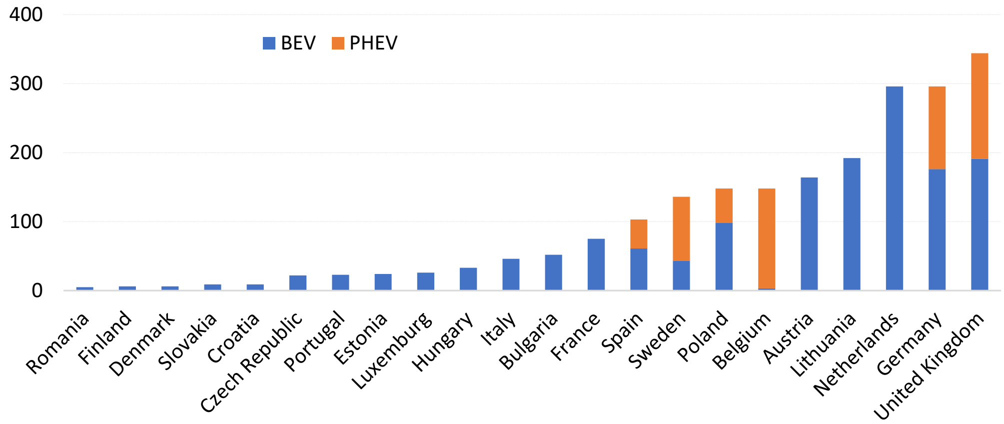


Figure A.6: European electric bus fleet 2017 [7].

The electric bus fleet in Europe 2017 as by ZeEUS and the UITP VEI Committee, is presented in Table A.4 [1]. The dominating electric bus type was using a battery or fuel cell.

Table A.4: Share of electric bus types, and estimated numbers in gray from given total in 2017 [1].

	Share of electric buses	**Number**
Battery and fuel cell	70%	686
Trolley with battery	24%	235
Plug-in hybrid	6%	59
Total number of electric buses	-	980

A.6 Electric Bus Sales Projections

A.6.1 Bloomberg

In 2018, Bloomberg predicted that the global fleet of electric buses will triple from 2017 to 2025, as shown in Figure A.7, and that it will then constitute about 47% of the total city bus fleet in 2025 [149].

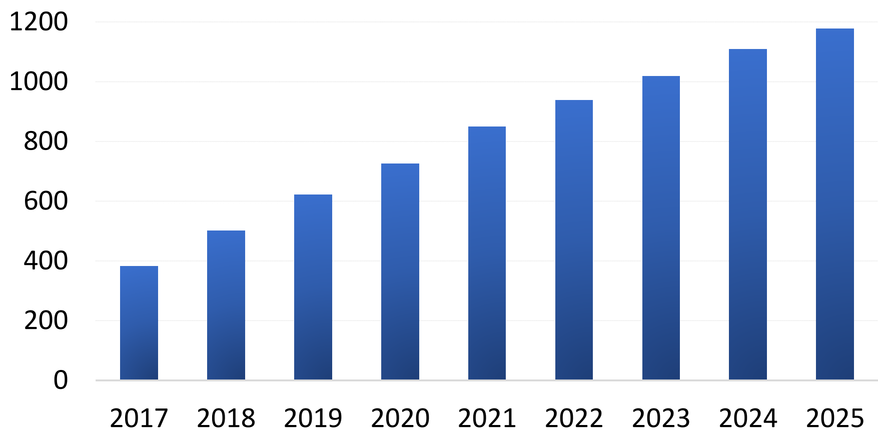


Figure A.7: Projection of global fleet of electric buses. 2017 386 000 sold units. Projection for 2025 almost 1.2 million, or 47% of global city bus fleet.

A.6.2 Navigant Research

In 2016, Navigant Research projected that battery electric drive drains will dominate the electric bus segment between 2016 and 2026, as shown in Figure A.8 [11].

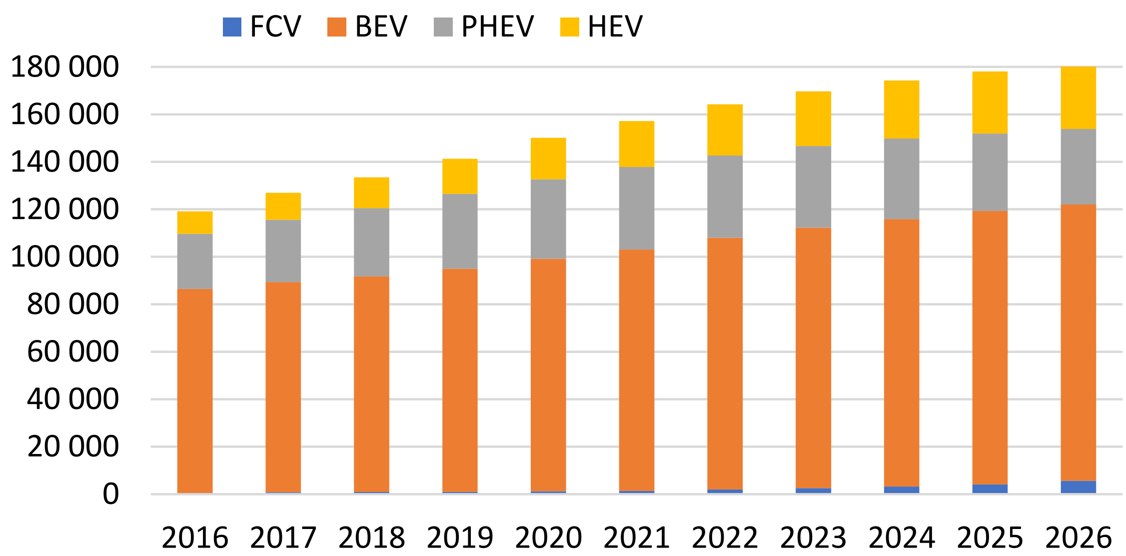


Figure A.8: Projection of drive train type in global fleet of electric buses, between 2016 ad 2026, by Navigant Research in 2016 [11].

A.6.3 Statista (Frost & Sullivan)

According to Statista with the help of Frost & Sullivan, the market share of hybrid and electric bus sales is expected to be the highest in China in 2022 [9]. They also expect the fleet to increase by about 69% and 177% in Europe and North America between 2022 and 2025 [10].

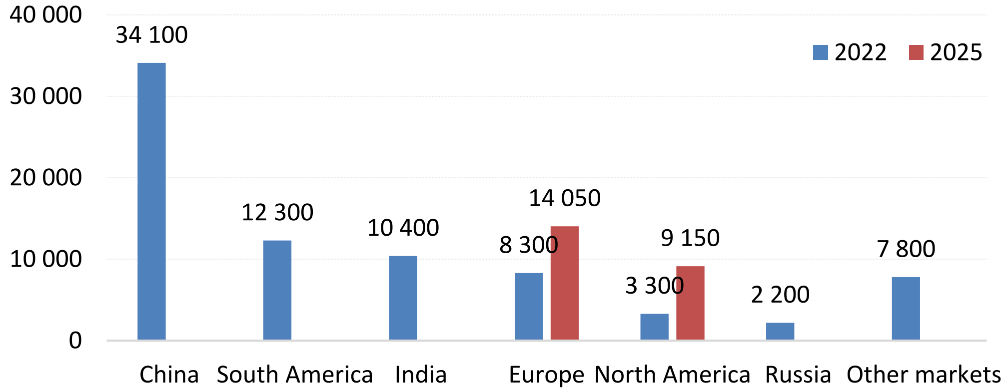


Figure A.9: Predicted hybrid and electric bus sales in 2022 and 2025 by Statista with the help of Frost & Sullivan in 2016 [9, 10]

A.6.4 ZeEUS and the UITP VEI Committee

ZeEUS and the UITP VEI Committee's scenarios for how the urban bus market will evolve in Europe by propulsion technology is shown in Figure A.10 [1]. They predict the global sales of electric buses to grow at a rate of 33.5% annually for the period 2017- 2025, and in 2030 battery electric buses are predicted to constitute over half of the European bus market [1].

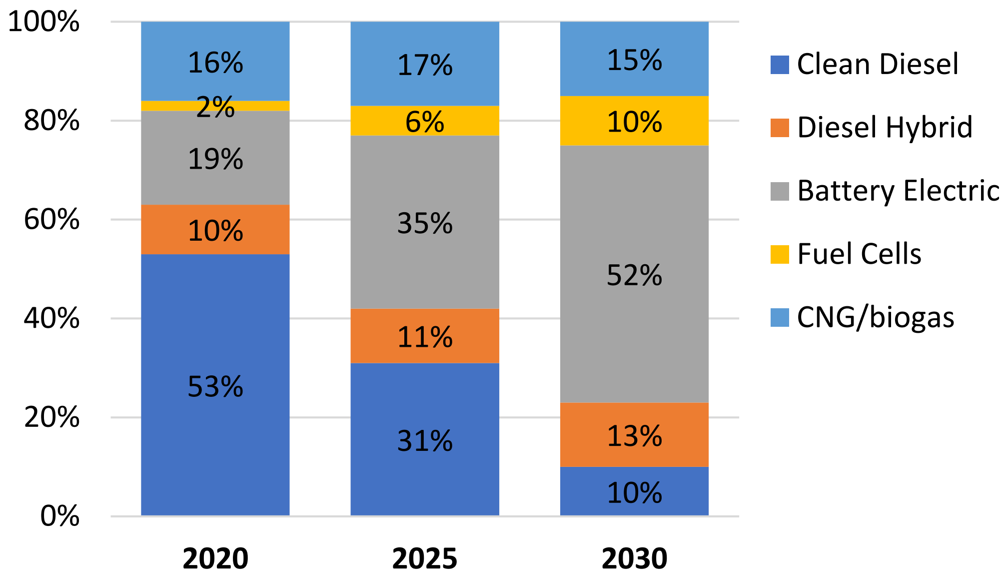


Figure A.10: ZeEUS and the UITP VEI Committee's scenarios for how the urban bus market will evolve in Europe by propulsion technology [1].

Appendix B

The ZeEUS eBus Report Data - Illustrated

In this chapter, data from the *ZeEUS eBus Report #2* [1] is aggregated for illustrative purposes.

B.1 Bus Data

B.1.1 Tested Buses Per Country

The total number of tested electric buses per country, is presented in Fig. B.1.

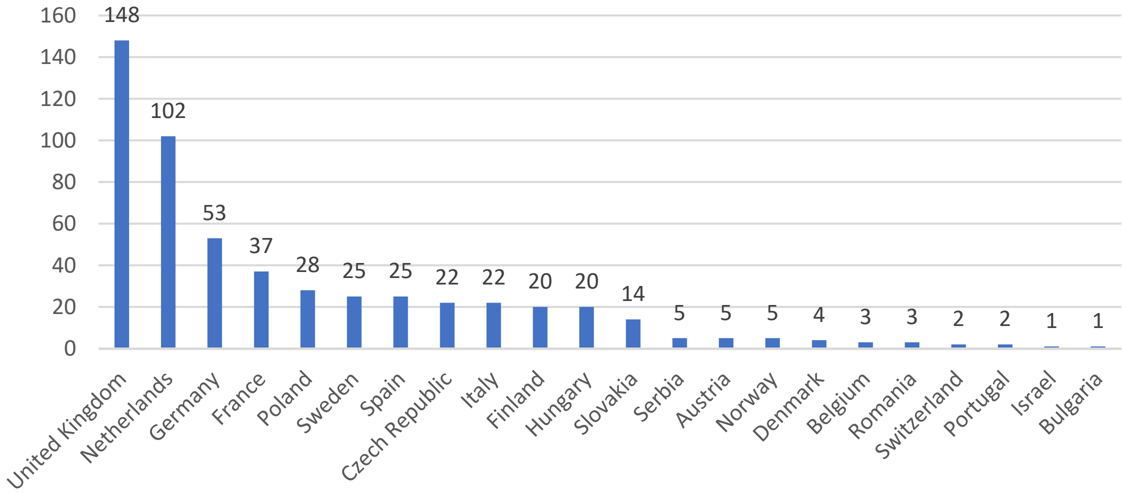


Figure B.1: Total number of electric buses tested per country [1].

B.1.2 Brand of Tested Buses

The total number of tested electric buses per brand, is presented in Fig. B.2.

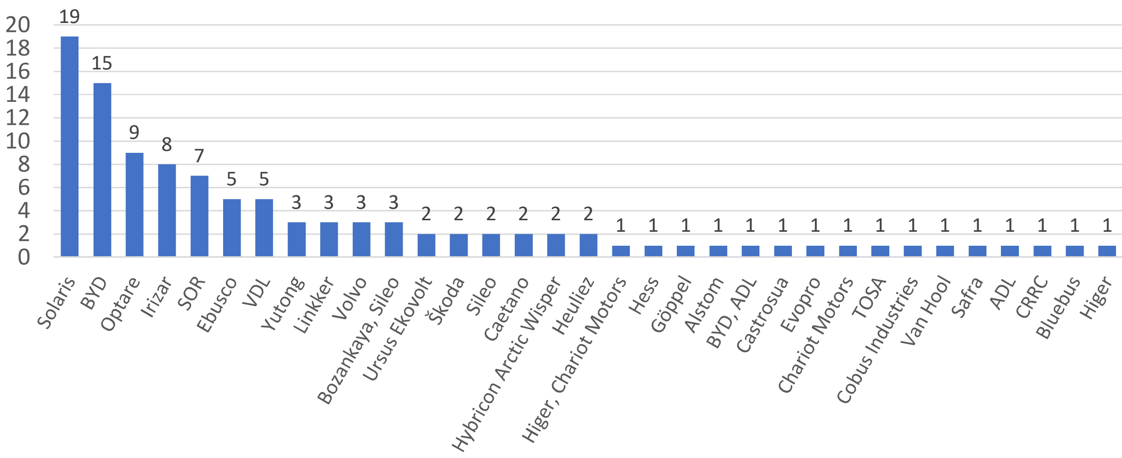


Figure B.2: Total number of electric buses tested per brand [1].

B.1.3 Models of Tested Buses

The total number of tested electric buses per model, is presented in Fig. B.3.

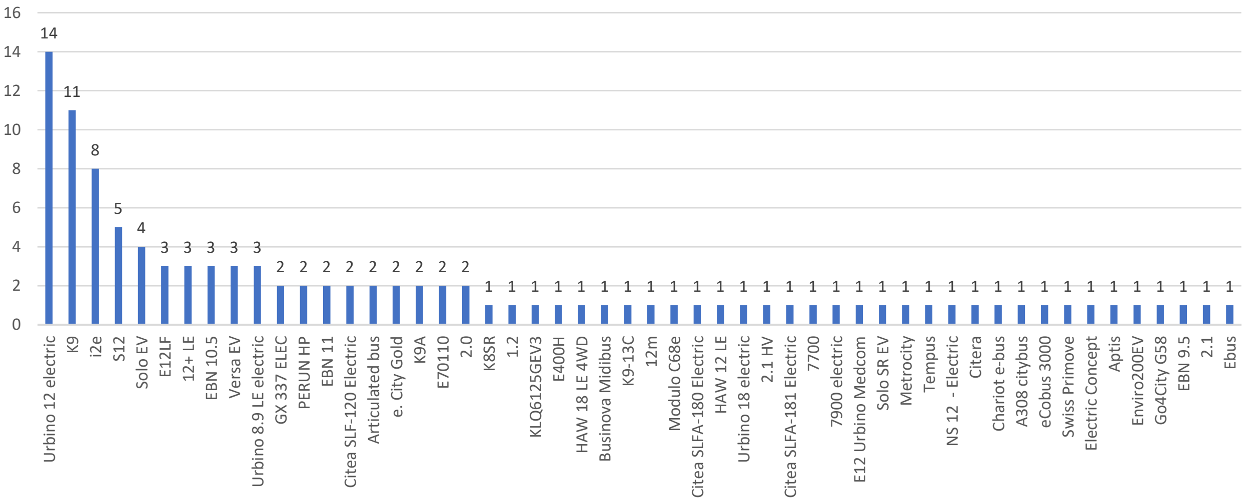


Figure B.3: Total number of electric buses tested per model [1].

B.1.4 Length of Tested Buses

The total number of tested electric buses per bus length, is presented in Fig. B.4.

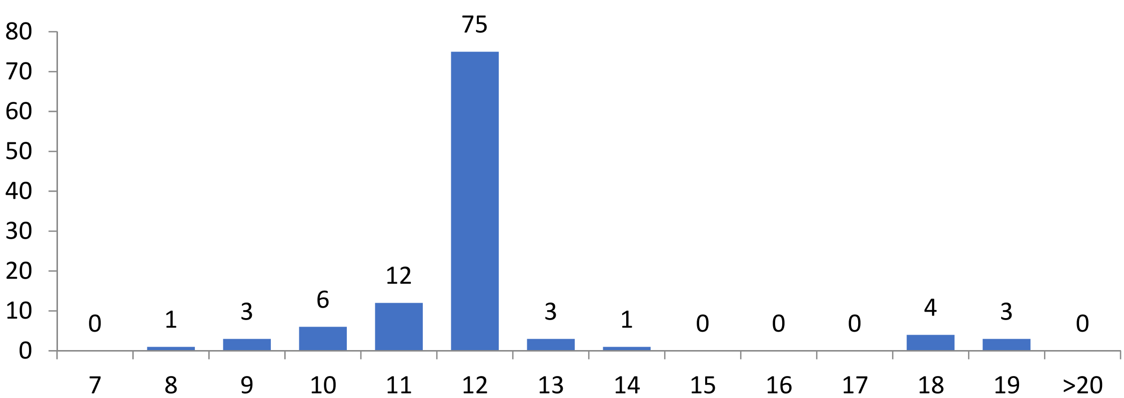


Figure B.4: Total number of electric buses tested per bus length (in bins of 1 m) [1].

B.1.5 Battery Energy Capacity of Tested Buses

The battery energy capacity of the tested buses, is presented in Fig. B.5.As can be seen the spread is wide; 10-380 kWh.

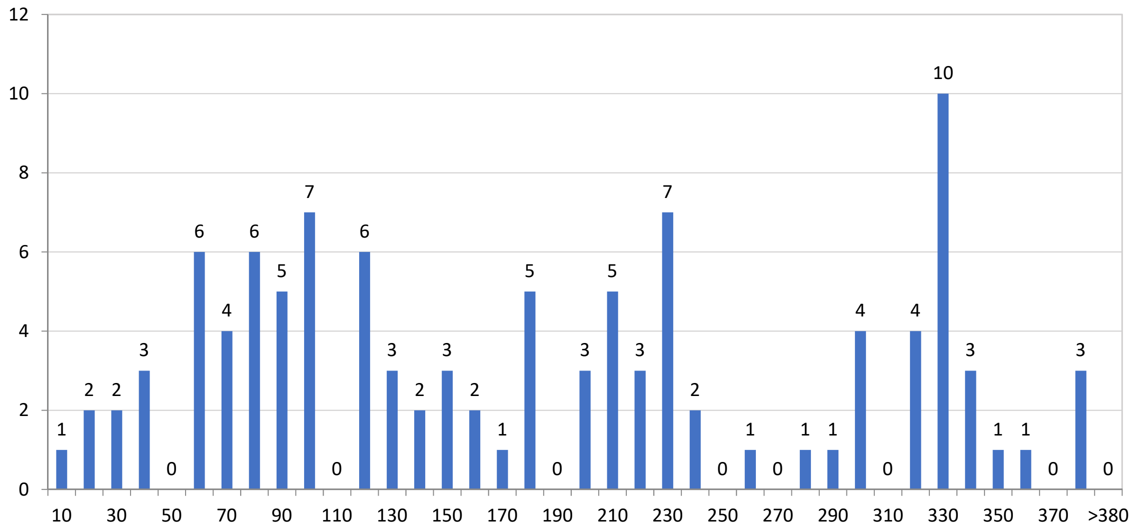


Figure B.5: The battery energy capacity of the tested buses (in bins of 10 kWh) [1].

B.1.6 Passenger Capacity of Tested Buses

The passenger capacity of the tested buses, is presented in Fig. B.6. Also here the spread is wide with most common values between 50-95.

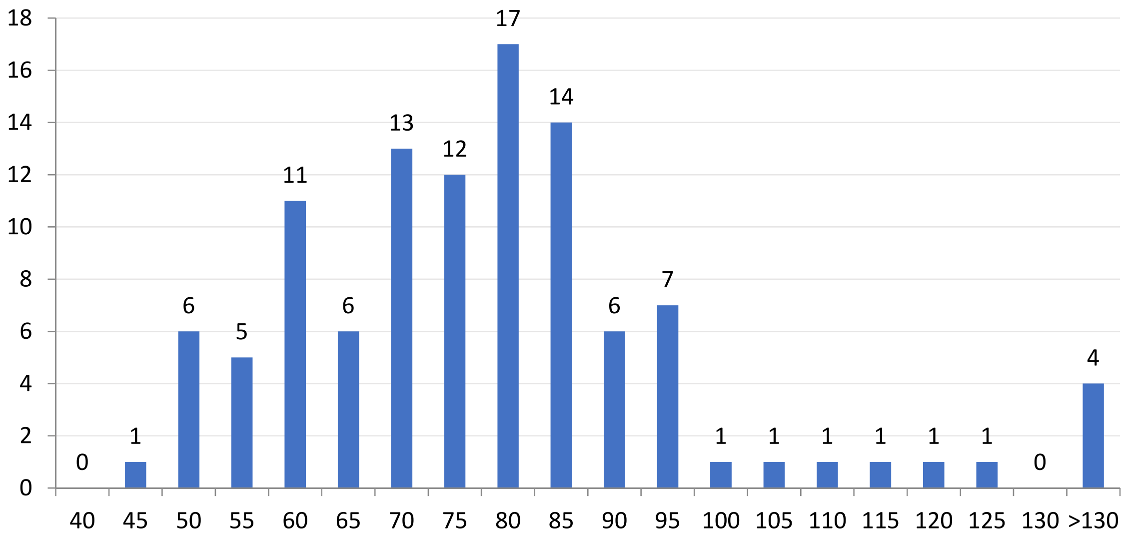


Figure B.6: The passenger capacity of the tested buses (in bins of 5) [1].

B.2 Bus Line Data

B.2.1 Length of Bus Lines

The length bus lines, is presented in Fig. B.7.

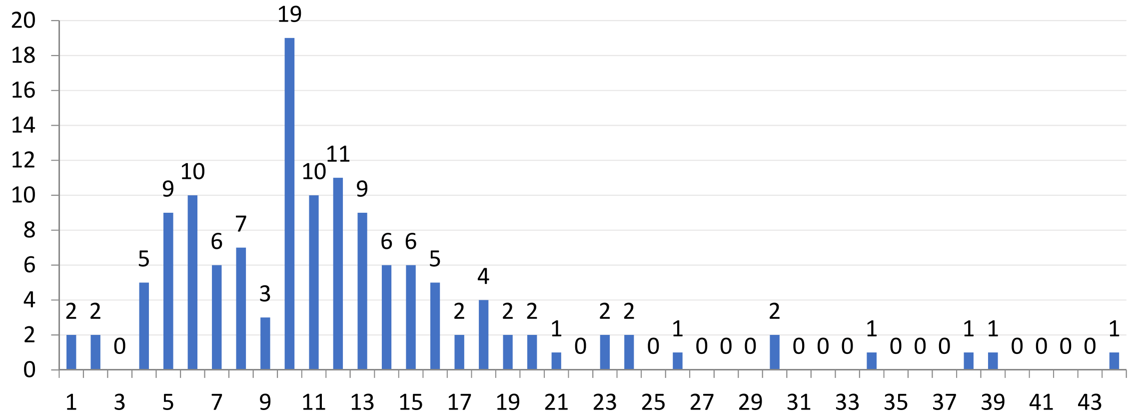


Figure B.7: The length bus lines (in bins of 1 km) [1].

B.2.2 Average Speed of Bus Lines

The average speed of the bus lines, is presented in Fig. B.8.

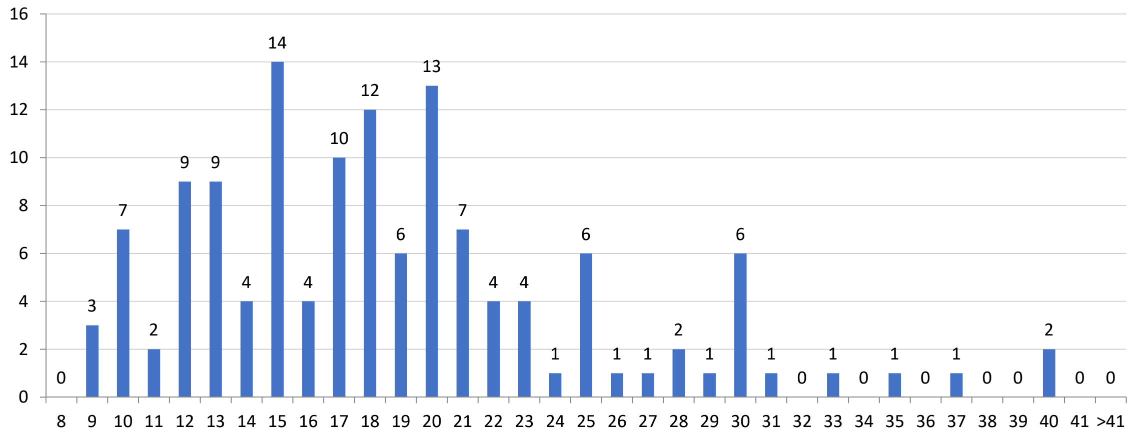


Figure B.8: The average speed of the bus lines (in bins of 1 km/h) [1].

B.2.3 Daily Hours of Operation

The total number of hours daily operated on the bus lines, is presented in Fig. B.9.

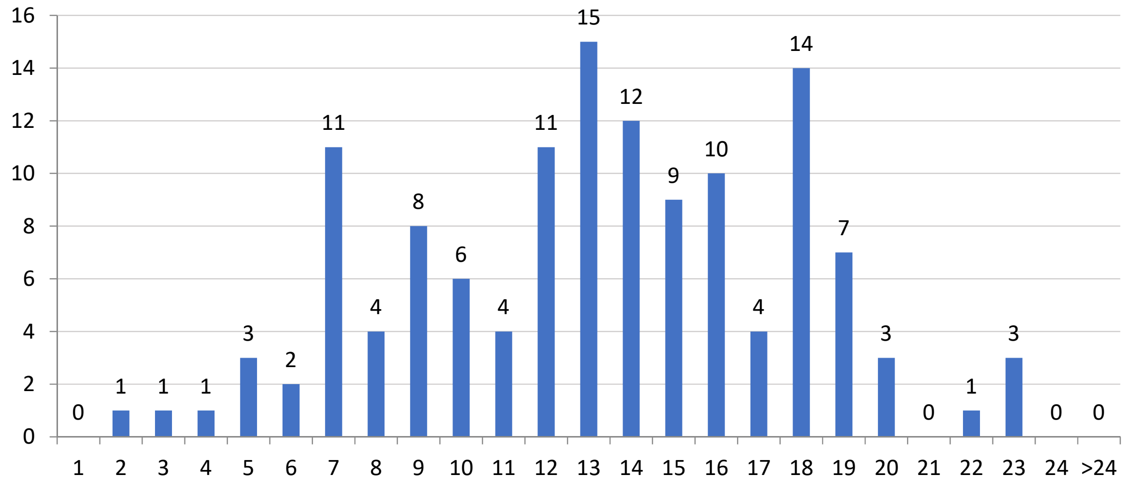


Figure B.9: The total number of hours daily operated on the bus lines (in bins of 1 h) [1].

B.2.4 Daily Driven Distance

The total driven distance (km) per vehicle per day, is presented in Fig. B.10.

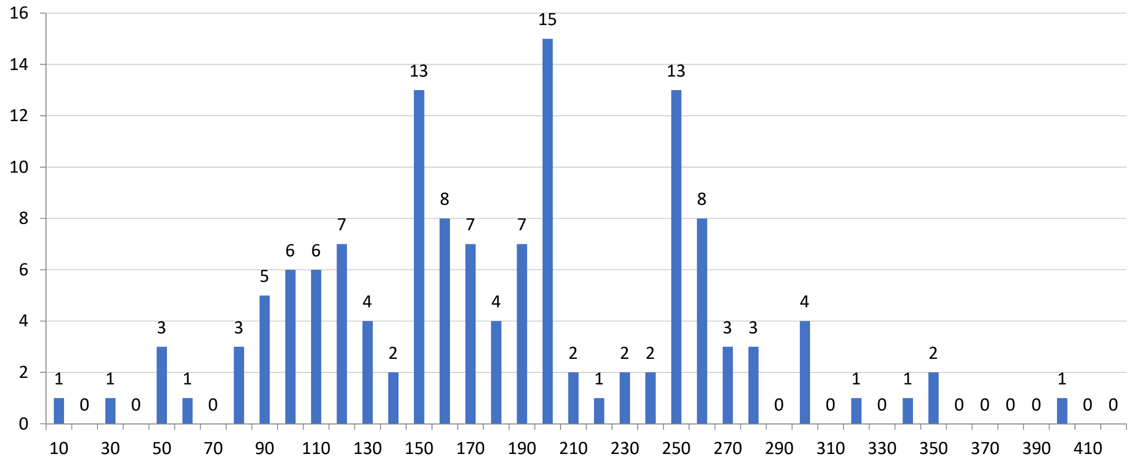


Figure B.10: The total driven distance (km) per vehicle per day (in bins of 10 km) [1].

Appendix C

BEV Bus Specifications

In this appendix, the specifications for 53 found city buses shorter than 10m and longer than 13m are listed in section C.1, and 17 battery electric coach buses are listen in section C.2.

C.1 City BEV Buses <10 m and >13 m

In this work, also battery electric buses shorten then 10m and longer than 13m were observed. Their origin, brand and model names are listen in Table C.1, along with a few selected specification parameters regarding curb weight, gross vehicle weight, maximum allowed number of passengers length, top speed and maximum grade.

Table C.1: Battery electric city buses, **shorter than 10 m and longer than 13 m**.

	Bus Brand	**Bus Model**	**Curb Weight (kg)**	**Max./ Gross Weight (kg)**	**Max. Pass.**	**Length (m)**	**Top Speed (km/h)**	**Max. Grade (%)**	**Tot. EM Peak Power (kW)**
CN	Anyuan	A8s PK6853BEV				8.5[150]			
CN	Anyuan	F8 PK6800BEV				8.1[150]			
BY	Belkommunmash	433 Vitovt Max Electro	17 600 [151]	28 000[151]	153[151]		60[151]		
FR	Bollore	Bluebus 6m	4 366 [76]	6 170[152]	22[152]	5.5[152]	50[152]		
TR	Bozankaya A.S.	Sileo S18		28 000[153]	135[153]	18.3[153]	75[153]		500 [87]
TR	Bozankaya A.S.	Sileo S25		39 000[154]	210[154]	24.4[154]	75[154]		500 [87]
CN	BYD (Europe)	18m		28 000[155]	150[155]	18.3[155]	70[155]	15[155]	300[155]
CN	DFAC	EQ6810CACBEV				8.1 [30]	69 [30]		
CN	DFAC	EQ6810CACBEV1				8.1 [30]			
NL	Ebusco	18m LF-414-HV-3/4		19 500 [1]	125 [1]	18.0 [1]	80 [1]		250 [87]
HU	Evopro	c48 minimo	4 750 [156]	8 300[157]	48[156]	6.5[156]			160[156]
HU	Evopro	Modulo C68e medio	6 700 [156]	10 350 [1]	68[156]	8.0[156]	65 [1]		160[156]
HU	Evopro	Modulo C88e optimo	7 550 [156]	11 050 [1]	88[156]	9.5[156]	65 [1]		160[156]
CN, CA	Foton & TM4	BJ6180EVCA			144[158]	18.0[158]			250[159]
CA	GreenPower	EV250		14 969[160]		9.8 [39]	97[160]		
CA	GreenPower	EV400				13.7 [39]			
CN	Guangtong	GTQ6601BEVB1				6.0 [40]			
CN	Guangtong	GTQ6690BEVB1				6.0 [40]			
CN	Guangtong	GTQ6768BEVB1				7.6 [40]			
CN	Guangtong	GTQ6802BEVB1				7.6 [40]			
CN	Guangtong	GTQ6858BEVB2				7.6 [40]			
CN	Guangtong	GTQ6858BEVBT2				7.6 [40]			
CN	Guangtong	GTQ6123BEVBT	9 000 [40]	13 500 [40]	69 [40]	8.5 [40]	69 [40]		
CH	HESS	TOSA BGT-N2D		29 000 [1]	142 [1]	18.7 [1]	80 [1]		240 [1]
SE	Hybricon	HAW 18 LE		28 000 [44]	104 [44]	18.0 [44]	80 [1]		728 [44]
SE	Hybricon	HAW 18 LF		28 000 [44]	110 [44]	18.0 [44]			728 [44]
ES	Irizar	ie tram (prev. i2e 18m)		28 000 [1]	155 [45]	18.4 [1]	85 [1]	18 [45]	
TR	Karsan	Atak Electric		11 000[161]	57[161]	8.2[161]		24[161]	230[161]
TR	Karsan	Jest Electric		5 000[162]	22[162]	5.9[162]	70[162]	25[162]	125[162]
CN	King Long	XMQ6662G				6.7 [46]	69 [46]	15 [46]	
CN	King Long	XMQ6706G EV				7.0 [46]	69 [46]	12 [46]	150 [46]
CN	King Long	XMQ6802G EV				8.0 [46]	69 [46]	15 [46]	
CN	King Long	XMQ6850G EV				8.5 [46]	69 [46]	15 [46]	
US	New Flyer	60" 18m	24 091 [163]		123 [51]	18.3 [51]			
GB	Optare	Solo EV Slimline		10 780 [1]	58 [53]	9.3 [53]	80 [1]		220 [53]
TR	Otokar	Doruk Electra		13 500 [1]	55 [1]	9.3[164]	90[164]		103[164]
FR	PVI	Oréos 2X			22[165]	7.0[165]	90[165]	23[166]	
FR	PVI	Oréos 4X			49[165]	9.0[165]	90[165]	23[167]	
IT	Rampini	E60			35 [56]	6.0 [56]			
IT	Rampini	E80		19 000 [57]	70 [57]	7.8 [56]			
PL	Solaris	Urbino 18 electric		30 000 [1]	129 [1]	18.0 [62]	80 [1]		250 [87]
PL	Solaris	Urbino 8.9 LE electric		16 000 [1]	65 [1]	9.0 [1]	80 [1]		170 [1]
CZ	SOR	EBN 8		16 500 [64]		8.0 [64]	80 [64]		
CZ	SOR	EBN 9.5		16 500 [64]		9.8 [64]	80 [64]		
TR	TEMSA	Temsa MD9 electriCITY		14 000 [1]	59[168]	9.5[169]	90 [1]	20[170]	200 [1]
PL	URSUS	City Smile 18m		28 000 [1]	104 [1]	18.0 [1]	100 [1]		1456 [91]
PL	URSUS	City Smile 8.5m	8 000 [67]	13 000 [1]	61 [1]	8.5 [1]	70 [1]		250 [84]
BE	Van Hool	Exqui.City 18m		28 000 [1]	117 [1]	18.6 [1]	70 [1]		320 [1]
NL	VDL	Citea LLE-99 Electric	18 475 [68]	29 000 [68]		18.8 [68]			240 [86]
NL	VDL	Citea SLFA-181 Electric	18 195 [68]	29 000 [68]	145 [1]	18.0 [68]	80 [1]		210 [1]
NL	VDL	SLFA-187 Electric	18 315 [68]	29 000 [68]	143 [1]	18.2 [68]	80 [1]		210 [1]
SE	Volvo	8900 BE	19 585 [171]	28 765[171]	135[171]	18.6[171]			370[171]

Table C.2: Selected **Electric Motor** Data for battery electric city buses, **shorter than 10 m and longer than 13 m**. The abbreviation *nom.* stand for nominal.

	Bus Brand	Bus Model	Length (m)	Motor Supplier	Motor Model	Motor Type	Tot. EM Peak Power (kW)	Total Max EM torque (Nm)	Cont. Power (kW)
FR	Bollore	Bluebus 6m	5.5	[152]		IM [152]			
TR	Bozankaya A.S.	Sileo S18	18.3	ZF [153]	AVE 130 [153]	IM [87]	500 [87]	971 [87]	240 [87]
TR	Bozankaya A.S.	Sileo S25	24.4	ZF [154]	AVE 130 [154]	IM [87]	500 [87]	971 [87]	240 [87]
CN	BYD (Europe)	18m	18.3	BYD [1]	TYC-150A [88]	PMSM [77]	300[155]		
NL	Ebusco	18m LF-414-HV-3/4	18.0	ZF [1]	AVE 130 [87]	IM [1]	250 [87]	485 [87]	120 [87]
HU	Evopro	c48 minimo	6.5	Siemens [156]	1DB2016 [156]	PMSM [86]	160[156]	2 500 [156]	125[156]
HU	Evopro	Modulo C68e medio	8.0	Siemens [1]	1DB2016-1NB06 [1]	PMSM [86]	160[156]	2 500 [156]	125[156]
HU	Evopro	Modulo C88e optimo	9.5	Siemens [1]	1DB2016-1NB06 [1]	PMSM [86]	160[156]	2 500 [156]	125[156]
CN, CA	Foton & TM4	BJ6180EVCA	18.0	TM4 [159]	LSM280A HV3400 [159]	PMSM[158]	250[159]	3 500 [159]	160[158]
CA	GreenPower	EV250	9.8	Siemens [39]					130[160]
CA	GreenPower	EV400	13.7	Siemens [39]					
CN	Guangtong	GTQ6123BEVBT	8.5	Zhuhai Yintong [40]	YTP-MP90-W [40]				90 [40]
CH	HESS	TOSA BGT-N2D	18.7	ABB [1]		PMSM [18]	240 [1]	1 520 [1]	
SE	Hybricon	HAW 18 LE	18.0	Ziehl-Abegg [44]	SM530 60AL-30 [1]	SM [35]	728 [44]	23 600 [44]	
SE	Hybricon	HAW 18 LF	18.0	Ziehl-Abegg [44]	4 Wheel motors [44]	SM [35]	728 [44]	23 600 [44]	
ES	Irizar	ie tram (prev. i2e 18m)	18.4	Alconza, Irizar [45]		PMSM[172]		2 350nom. [1]	235 [45]
TR	Karsan	Atak Electric	8.2	TM4 [161]			230[161]	2 400 [161]	115[161]
TR	Karsan	Jest Electric	5.9	BMW [162]			125[162]		
CN	King Long	XMQ6706G EV	7.0			PMSM [46]	150 [46]		115 [46]
US	New Flyer	60" 18m	18.3	Siemens [163]	1DB2016 [163]	PMSM [86]	160 [86]	2500 [86]	160 [86]
GB	Optare	Solo EV Slimline	9.3	Magtec [1]		PM [53]	220 [53]	3 168 [53]	
TR	Otokar	Doruk Electra	9.3			IM [1]	103[164]	475 [164]	
FR	PVI	Oréos 2X	7.0	PVI [166]		IM [166]			47[166]
FR	PVI	Oréos 4X	9.0	PVI [167]		IM [167]			103[167]
PL	Solaris	Urbino 18 electric	18.0	TSA, ZF [1]	AVE 130 [87]	IM [1]	250 [87]	971 [87]	120 [87]
PL	Solaris	Urbino 8.9 LE electric	9.0	TSA [1]	TMF35-44-4 [97]	IM [1]	170 [1]	903nom. [1]	
TR	TEMSA	Temsa MD9 electriCITY	9.5	TM4 [1]		PM [1]	200 [1]	2 200 [1]	100[170]
PL	URSUS	City Smile 18m	18.0	Ziehl-Abegg [1]	530.60AL-30 [1]	PMSM [90]	728 [91]	10 800 [1]	452 [1]
PL	URSUS	City Smile 8.5m	8.5	TM4 [1]	LSM280AHV-3400-A1 [1]	PMSM [84]	250 [84]	3 400 [84]	170 [1]
BE	Van Hool	Exqui.City 18m	18.6	Siemens [1]	PEM 2016 [1]	PMSM [86]	320 [1]	5000 [1]	320 [86]
NL	VDL	Citea LLE-99 Electric	18.8	Siemens [68]	1DB2022 [68]	PMSM [86]	240 [86]	3 800 [68]	210 [68]
NL	VDL	Citea SLFA-181 Electric	18.0	Siemens [68]	1DB2022 [68]	PMSM [86]	210 [1]	3 800 [1]	210 [68]
NL	VDL	SLFA-187 Electric	18.2	Siemens [68]	1DB2022 [68]	PMSM [86]	210 [1]	3 800 [1]	210 [68]

C.2 Coach BEV Buses

Battery electric Coach buses were also found. Their origin, brand and model names are listen in Table C.3, along with a few selected specifications parameters regarding curb weight, gross vehicle weight, maximum allowed number of passengers length, top speed and maximum grade. This list is however not claimed to be comprehensive since coach bus data was not explicitly targeted. Instead the list can be seen as encountered examples while looking for city bus data.

Table C.3: Battery electric **Coach buses**.

	Bus Brand	Bus Model	Curb weight (kg)	Max./ Gross Weight (kg)	Max. Pass.	Length (m)	Top speed (km/h)	Max. Grade (%)	Total EM power (kW)
CN	Ankai	HFF6101K10EV		16 000[173]	45[173]	10.5[173]	100[173]		
AU	Avass	Augusta Turing		20 000[174]	49[174]	12.5[174]	100[174]		180[174]
AU	Avass	Augusta Turing 9.5 MT		14 500[175]	39[175]	9.5[175]	80[175]	20[175]	200[175]
CN	BYD (Europe)	13m		19 000[176]	59[176]	12.9[176]	90[176]	20[176]	360[176]
CN	BYD (SG)	C8	13 500 [25]	17 000 [25]	45 [25]	10.6 [25]	100 [25]	20 [25]	360 [25]
CN	BYD (SG)	C9	14 000 [25]	18 000 [25]	49 [25]	12.0 [25]	100 [25]	20 [25]	360 [25]
CN	DFAC	EQ6811LACBEV1				8.1 [30]			
CN	Dongfeng	EQ6100CLBEV2	11 200 [177]	16 500[177]	45[177]	10.5[177]	100[177]		160[177]
UG	Kayoola	Solar Bus			35[178]	9.1[178]	100[178]	18[178]	150[178]
CN	King Long	XMQ6706 EV			23 [46]	7.0 [46]	100 [46]	12 [46]	150 [46]
CN	King Long	XMQ6806 EV			26 [46]	8.0 [46]	100 [46]	12 [46]	150 [46]
CN	King Long	XMQ6110C EV			51 [46]	10.7 [46]	100 [46]		180 [46]
CN	Nanjing Jinlong	NJL6118BEV	13 300 [179]	17 835[179]	49[179]	11.0[179]	80[179]	20[180]	160 [98]
CN	Sunlong Shenlong	SLK6118ALE0BEVS6	12 000 [181]	16 400[181]	53[181]	11.0[181]	100[181]		200[181]
CN	YinLong	11m	11 600 [72]	16 500 [72]	49 [72]	10.7 [72]	100 [72]		
CN	Yutong	ICE12		19 400 [1]	59 [74]	12.4	100 [1]		350 [1]
CN	Zhong Tong	LCK6125EV		18 600 [75]	40 [75]	12.0 [75]	90 [75]		230 [75]

C.3 Not Included Bus Models

Table C.4 presents a list of electric bus models that have, do or will exist, but unfortunately not much data was found.

Table C.4: Not studied battery electric bus models, due to lack of data.

Country	Brand	Model	Comment
US	Astonbus	100% ELECTRIC City Bus	No data [182]
BY	Belkommunmash	420 Vitovt Electro	No data
CN	Bonluck	JXK6840B	8 m [183]
IT	Iveco	EuroPolis	Test bus year 2009, i.e. old data
LT, DE	Dancerbus	Dancer	12.0 m max. 70km/h, GVW 6500 kg, up to 93 pass. [1] [184]
UA	Electron Corporation	Electron E19 electric	12.1 m, max. 70km/h, GVW 19 000 kg, up to 90 pass. [1]
US	EPV	ECOSmart	No data [185]
CN	Jiangsu Alfa Bus	12m electric city	No data [186]
JP	Mitsubishi Heavy Industries	11m	Old data [187]
IT	TECNOBUS	Gulliver	5.8m, GVW 6075 kg, anticipated old data [188]
CN	Sunwin & Volvo	SWB6108EV	10.5 m [70]
SE	Scania	CityWide ELectric	12 m, 100 pass, 300 kW peak, 250kWh battery [189]